Three Year Summary Age and Growth Report

For

Sicklefin Chub (*Macrhybopsis meeki*)

Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River

Prepared for the U.S. Army Corps of Engineers – Northwest Division
By:

Patricia Herman, Andrew Plauck, Nick Utrup and Tracy Hill
U.S. Fish & Wildlife Service
Columbia National Fish & Wildlife Conservation Office
101 Park DeVille Drive, Suite A
Columbia, MO 65203

February 25, 2008

Executive Summary

Pallid sturgeon (*Scaphirhynchus albus)* have declined throughout the Missouri River since dam construction and inception of the Bank Stabilization and Navigation Project in 1912. After an evaluation of the condition and management of the Missouri River, it was concluded that altered flow and habitat conditions associated with current management practices on the Missouri River have resulted in a disturbed river ecosystem. In response, the U.S. Army Corps of Engineers has agreed to work with the U.S. Fish and Wildlife Service, as well as other state and federal agencies, to develop monitoring and restoration projects to avoid further jeopardizing the Missouri River ecosystem and help restore pallid sturgeon populations.

Because the pallid sturgeon is a known piscivore, native Missouri River fishes, which may serve as prey, are critical components of pallid sturgeon recovery in the Missouri River. Concordantly, an understanding of population dynamics of fishes in a highly modified system is critical for implementing management strategies to recover endangered species. As a result, one of the objectives of the pallid sturgeon recovery plan is to monitor native Missouri River fish species that are associated with the life history of the pallid sturgeon. Nine target species have been identified as associated with pallid sturgeon recovery, they include: shovelnose sturgeon (*Scaphirhynchus platorynchus*), blue sucker (*Cycleptus elongates*), sauger (S*ander canadensis*), sand shiner (*Notropis stramineus*), plains minnow (*Hybognathus placitus*), western silvery minnow (*Hybognathus argyritis*), sicklefin chub (*Macrhybopsis meeki*), speckled chub (*Macrhybopsis aestivalis*), and sturgeon chub (*Macrhybopsis gelida*). These target species have been collected for analysis of age, growth, and life history characteristics.

The age and growth analysis of target species has been divided among field stations involved with the Pallid Sturgeon Population Assessment and Associated Fish Community Monitoring Program for the Missouri River. Nebraska Game & Parks Commission has analyzed shovelnose sturgeon spines; South Dakota blue sucker, Missouri Department of Conservation sauger, sand shiners, western silvery minnows, and plains minnows, and Columbia National Fish & Wildlife Conservation Office has been responsible for sicklefin, speckled, and sturgeon chubs.

We analyzed age, growth, and life history characteristics of sicklefin chubs collected throughout the Missouri River from 2004 thorough 2006. The program area encompasses the Missouri River from Fort Peck Dam, Montana, at river mile (RM) 1771.5, downstream to the confluence of the Missouri and Mississippi Rivers near St. Louis, Missouri (RM 0), as well as the lower reach of the Kansas River near Kansas City, Missouri. There are two geographically distinct reaches of the Missouri River basin recognized as the “Upper Sampling Universe” and “Lower Sampling Universe”. The Upper Sampling Universe is the unchannelized portion of the upper Missouri River, above Ft. Randall Dam (RM 880.0), and the Lower Sampling Universe is the impounded and channelized portion of the lower Missouri River.

Sampling was conducted in accordance with Standard Operating Procedures established by a panel of representatives from various state and federal agencies involved with pallid sturgeon recovery on the Missouri River. Chub scales were collected only during fish community season (July 1 thorough October 31). Sicklefin chubs collected for age and growth analysis were preserved in 10% formalin solution with all appropriate information (*i.e*., Date, Field Office, Segment Number, Unique Identifier, Fish ID and Species) recorded for later analysis. All scales were digitally read using a digital camera attached to a dissecting microscope. Ages were determined by total number of annuli per scale. Radii and annular measurements were taken from the focus to the longest anterior edge on all scales. Sicklefin chub data were $\log_{10}+1$ transformed for normality and an analysis of variance was used to test for significant differences between segments. Tukey's test ($\alpha = 0.05$) was used to compare and group means.

During 2004 through 2006, aging structures from 574 sicklefin chubs were analyzed from seven segments (Table 3). The most effective gear for capturing sicklefin chubs throughout the Missouri River was a 16 foot otter trawl. Mean back calculated total length-at-last annulus for all years combined showed faster growth in the upper-most segments. Length frequency distributions for sicklefin chubs were compared between segments for each year and peaks in small fish (20 mm) in 2004 and 2005(Appendix B). The majority of sicklefin chubs captured were age 1 and age 2 fish. Age 0 fish were under-represented in the samples, possibly due to sampling bias or inability to identify at smaller sizes.

It was difficult to discern differences in mean lengths between years due to low and unequal sample sizes in all segments. Age one and two sicklefin chubs were larger in the upper segments. By age three the differences between upper and lower segments were unnoticeable.

Additional analysis of all chub species throughout the Missouri River using a multivariate analysis of variance (MANOVA) showed a significant effect of age and segment ($P < 0.05$) on length-at-age for chubs less than age 3 (Appendix D). Mean length-at-age for age 1 and age 2 fish were 15% and16% longer, respectively, in the upper sampling universe versus lower sampling universe.

Age and growth analyses of all chub species has allowed for an evaluation of annual and long-term trends in population abundance and geographic distribution throughout the Missouri River. Data show that significant size differences exist between segments, species, and years. Because chub species show critical ontogenetic growth periods from age 0 to age 1, conservation of habitats used by chubs in the first year of life will likely improve survival and recruitment. Improvement in survival and recruitment of prey species, such as chubs, is imperative to the continued recovery of pallid sturgeon and further restoration of the Missouri River.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Introduction

Pallid sturgeon (*Scaphirhynchus albus)* have declined throughout the Missouri River since dam construction and inception of the Bank Stabilization and Navigation Project in 1912 (Carlson et al. 1985). Loss of habitat, reduced turbidity, increased velocity, loss of natural flows, reduction in forage, increased hybridization and inadequate reproduction and recruitment are factors having contributed to the decline of the pallid sturgeon and other native species (Pflieger and Grace 1987). Since 1996, surveys conducted throughout the Missouri and Mississippi Rivers show an increase in hybridization and continued decline of pallid sturgeon relative abundance (Grady et al. 2001, Doyle and Starostka 2003, Doyle and Starostka 2004).

In an independent scientific evaluation of condition and management of the Missouri River, the National Research Council (2002) concluded that altered flow and habitat conditions associated with current management practices on the Missouri River have resulted in a disturbed river ecosystem. Similar conclusions presented in the U. S. Fish and Wildlife Service Biological Opinion recommended, in part, that Army Corps of Engineers (COE) initiate modified flow regimes by 2003 to avoid jeopardizing three listed species (endangered pallid sturgeon and least tern; threatened piping plover) and begin restoring the river's ecological processes. The COE is responsible for monitoring and evaluating biotic responses of pallid sturgeon to operational and habitat changes on the Missouri River (USFWS 2000). Habitat restoration, higher spring and lower summer flows combined with adaptive management are recommended measures to restore pallid sturgeon populations on the Lower Missouri River. Monitoring sturgeon populations will provide vital information needed to guide restoration of habitat, hydrology and fish communities in the Lower Missouri River.

In response to the 2000 Missouri River Biological Opinion, the COE is developing monitoring and restoration projects to avoid jeopardizing and to restore pallid sturgeon populations. As part of their implementation plan, the COE is working with the U. S. Fish and Wildlife Service (USFWS) and state resource agencies to develop and conduct a pallid sturgeon monitoring and assessment program. The objectives of this program are as follows:

1. Document annual results and long-term trends in pallid sturgeon population abundance and geographic distribution throughout the Missouri River System.
2. Document annual results and long-term trends of habitat use of wild pallid sturgeon and hatchery stocked pallid sturgeon by season and life stage.
3. Document population structure and dynamics of pallid sturgeon in the Missouri River System.
4. Evaluate annual results and long-term trends in native target species population abundance and geographic distribution throughout the Missouri River system.
5. Document annual results and long-term trends of habitat usage of the native target species by season and life stage.
6. Document annual results and long-term trends of all non-target species population abundance and geographic distribution throughout the Missouri River system, where sample size is greater than fifty individuals.

Because the pallid sturgeon is a known piscivore (Gerrity et al. 2006), native Missouri River fishes that may serve as prey are critical components of pallid sturgeon recovery in the Missouri River ecosystem. To address the fourth objective, nine target species have been identified for analysis of age, growth, mortality and life history characteristics. A representative group of native Missouri River fishes have been selected in an effort to detect improvements in the warm water benthic fish community. Among the selected species are: shovelnose sturgeon *Scaphirhynchus platorynchus*, blue sucker *Cycleptus elongatus*, sauger S*ander canadensis*, sand shiner *Notropis stramineus*, plains minnow *Hybognathus placitus,* western silvery minnow *Hybognathus argyritis*, sicklefin chub *Macrhybopsis meeki*, speckled chub *Macrhybopsis aestivalis* and sturgeon chub *Macrhybopsis gelid.*

The age and growth analysis of target species has been divided between field stations involved in the Pallid Sturgeon Population Assessment and Associated Fish Community Monitoring for the Missouri River. Nebraska Game & Parks Commission is analyzing shovelnose sturgeon spines. South Dakota is performing analyses on blue sucker spines. Missouri Department of Conservation (MDC) is analyzing sauger scales, spines and otoliths. The MDC office is also analyzing scales from sand shiners, western silvery minnows, and plains minnows. Columbia National Fish & Wildlife Conservation Office is responsible for the age and growth analysis of sicklefin chub, speckled chub and sturgeon chub scales for years 2004 – 2006. Montana Fish, Wildlife and Parks has contracted to perform age and growth analyses for chub species from 2007.

An understanding of population dynamics of fishes in a highly modified system is critical for implementing management strategies to recover endangered species. Natural and unnatural environmental gradients that occur in large river systems may influence life history characteristics in fishes. River systems can vary in productivity due to physical, chemical and biological factors (Braaten and Guy 2002). In a vast and strongly regulated system like the Missouri River, productivity may be reflected in growth rates in and among fish species. By looking at growth rates of target species from all segments of the river, life history characteristics may be gleaned and potentially applied in the recovery of pallid sturgeon throughout its natural range. *Macrhybopsis* species were selected for analysis because of their role as prey items for juvenile pallid sturgeon (Gerrity et al. 2006).

The sicklefin chub is a member of the Cyprinidae or minnow family. Sicklefin chubs are a long, slender minnow characterized by long falcate (sickle-shaped) pectoral fins. The sicklefin chub is usually yellowish or tan colored on the back and silvery-white on the belly with a snout protruding slightly beyond the mouth. A single pair of maxillary barbels is located at the corners of the mouth. In combination with long fins, sicklefin chubs have a fusiform shape and small eyes adapted for living in large turbid rivers with high velocity habitats. Sicklefin chubs are typically found in the main channels over fine gravel or sandy substrates. Historically, sicklefin chubs were found in the mainstem of the Missouri River, tributaries of the Missouri River and in the Mississippi River downstream of the confluence. Average adult length ranges from 3.6 to 10.1 centimeters (1.4 to 4.0 inches) with the average adult weight ranging from 0.6 to 6.2 grams (0.02 to 0.2 ounce). The sicklefin is a relatively short-lived species with a small percentage of the population reaching age 4 (Pflieger 1997).

Study Area

The Program area encompasses the Missouri River from Fort Peck Dam, Montana at Rivermile (RM) 1771.5 downstream to the confluence of the Missouri and Mississippi Rivers near St. Louis, Missouri (RM 0) and the lower reach of the Kansas River. The 2000 Opinion divides the Program area into river and reservoir segments. The segments included in the sampling efforts are: Segment 1, (Fort Peck Dam, Montana, RM 1771.5 to the Confluence of the Milk River, RM 1760.0), Segment 2 (Confluence of the Milk River, RM 1760.0 to Wolf Point, RM 1701.0), Segment 3 (Wolf Point, RM 1701.0 to the confluence of the Yellowstone River, RM 1582.0), Segment 4 (Confluence of the Yellowstone River to the headwaters of Lake Sakakawea, North Dakota, RM 1568.0), Segment 5 (Fort Randall Dam, South Dakota, RM 880 to the confluence of the Niobrara River, RM 845.0), Segment 6 (confluence of the Niobrara River to the headwaters of Lewis & Clark Lake, RM 825.0), Segment 7 (Gavins Point Dam, RM 811.0 to Lower Ponca Bend, Nebraska, RM 750.0), Segment 8 (Lower Ponca Bend, RM 750.0 to the confluence of the Platte River, RM 595.0), Segment 9 (Confluence of the Platte River, RM 595.0 to the confluence of the Kansas River, Missouri, RM 367.5), Segment 10 (confluence of the Kansas River, RM 367.5 to the confluence of the Grand River, RM 250.0), Segment 13 (confluence of the Grand River, RM 250.0 to the confluence of the Osage River, RM 130.0) and Segment 14 (confluence of the Osage to the confluence with the Mississippi River, RM 0.0) (Table 1, Figure 1)(Drobish 2007).

The team recognizes two geographically distinct reaches of the Missouri River basin. The Fort Peck Reach (segments 1-4) and the Fort Randall to the mouth reach (segments 5-14) are recognized as the “Upper Sampling Universe” and “Lower Sampling Universe” respectively. These reaches are characterized by geographic, hydrologic and management differences. The upper universe, though impounded, is not channelized; and is influenced by reservoir discharge resulting in cold water temperatures, variable flows and meandering channels. Certain segments of the upper universe also have a remnant population of wild pallid sturgeon (Kallemeyn 1983, Keenlyne 1989). The lower universe includes the impounded portion and the channelized sections of the Missouri River. The lower universe is widely ranging in habitat (natural and manufactured) and has highly regulated management regimes.

Historically, the Missouri River was very wide and shallow, containing meandering channels with many islands and snags (Grady and Milligan 1998). Today, portions of the profoundly altered Missouri River and many of its tributaries are characterized by deep reservoirs and narrow, stabilized channels. Alterations to the river were executed by the COE to serve as a navigation channel for barge traffic. High levees and armored banks not only serve to mange the navigation channel, but also protects adjacent farm land. Revetted banks and dikes line the lower portion of the river resulting in a self-scouring channel. Alterations to the river have come at a price. While management has resulted in power generation, recreational areas and stabile farmland, alterations have negatively impacted flow regimes, water quality, and habitat heterogeneity (Dieterman and Galat 2004). Over the last two decades, the COE has made efforts to diversify habitats by notching dikes, creating “pilot channels” on the flood plain and by releasing waters to imitate flood events. In recent years, much emphasis has been given to these dike modification projects and many of the existing dikes in this reach of river have received some modifications. Notches are now deeper and wider than what previously existed and can change how water is diverted into the bank allowing erosion or deposition to occur at varying degrees. Dike types vary in design but in general, outside bends contain L-shaped dike pointing down stream while dikes on the inside bend are more wing shaped, projecting straight into the channel and slightly downstream. The subsequent habitats that exist behind these dikes vary widely and fish species may use them according to biologically different needs. Some remnant historical habitats, such as sand bars and natural gravel shoals, still exist at different water stages. These remnant habitats are important biologically not only for the pallid sturgeon but also the supporting prey species (*i.e.*, chubs).

Methods

Sampling was conducted in accordance with Standard Operating Procedures established by a panel of representatives from various state and federal agencies involved with pallid sturgeon recovery on the Missouri River (Drobish, 2007). The sampling guidelines were meant to be adaptive and have been modified to ensure sampling efficiency and scientific accuracy.

Sample Site Selection

Each segment represented a sampling replicate. Segments were divided into bends that were defined as the crossing of the thalweg from one bank to the other and back. Within each segment, 25% of bends were randomly selected and sampled with a suite of gears. For years 2003 – 2006 the bends were randomly selected at the level of the river using a non-stratified sampling design. Sampling efforts were divided into two season, Sturgeon Season (1 November – 30 June) and Fish Community (1 July – 31 October). In years 2003 – 2005, bends were randomly selected for each season. In 2006, the sampling design was changed to randomly selecting bends only once per sampling year where the same bends were sampled in both seasons. Age structures (scales) were only collected from chub species during the fish community season (Table 2). The river was categorized into distinct river components called mesohabitats which exist within macrohabitats. Each mesohabitat was sampled twice within each macrohabitat. When a diversity of habitats was not available, a minimum of eight samples were used to ensure some consistent level of effort per bend.

Sampling Gear

Otter trawls (OT or OT16) were pulled downstream with a jet powered stern trawler. Trawls were most effective on sand bars off the main channel, but could be used in some POOL habitat as a wild (non-standardized) option. Trawls were not used on outside bend revetment or in the thalweg for safety reasons.

Beam trawls (BT) were towed in POOL habitat behind dikes with a stern trawler. Samples were complicated by swirling currents behind dikes and the driver's experience in estimating when the beam was touching the bottom. Distance of the tow was calculated based on when the net hit bottom and when it returned to the boat. The BTs were used exclusively in POOL habitat because of their durability when encountering snags. Beam trawls were dropped from standard sampling in 2006 due to gear development of larger, more efficient otter trawls.

Mini-fyke nets, push trawls and seines were gears used solely in fish community season. These nets are more effective at capturing smaller fish, which are more abundant after the spawning season. Mini-fykes (MF) were set on mud bars behind dikes and on sand bars in the main-channel and could only be applied in emergent bar habitat. Thus, all bends did not receive similar amounts of effort.

Push trawls (POT02) were pushed using an outboard jet boat and forward facing outriggers. This sample design targeted depths between 0.3 meters and 1.2 meters. All bends received standardized levels of effort. Distances sampled ranged from 15 meters to 150 meters habitats depending on microhabitat and distance necessary for acquiring a representative subsample. Use of push trawls as an evaluation gear began in 2006.

Bag-seines (BS) were pulled wherever wadable substrate and depths existed. Many methods of seines deployment were used, including; half or whole arcs, upstream or downstream pulling. Bag seines were removed from standard sampling in 2006 due to their similarity of results with mini-fyke nets.

Sampling gear dimensions as described in Missouri River Standard Operating Procedures for Sampling and Data Collection (January 2007):
Otter Trawl : Custom *Skate* design = 4.9 m (16 ft.) width, 0.9 m (3 ft.) height and 7.6 m (25 ft.) length. Inner mesh of 6.35 mm (1/4 inch) bar, #18 polyethylene twine and an outer mesh of 38.1 mm (1.5") bar, #9 polyethylene twine, cod-end opening of 406.4 mm (16"). Trawl doors = 19.1 mm (3/4") marine plywood, 762 mm (30") by 381 mm (15") and 12.7 mm (1/2 inch) thick heavy steel runners. Weight = 7.9 m (26 ft.) long 3.2 mm (1/8 inch) tickler chain attached to the bottom front of net.
Beam trawl: Custom design = 2.0 m (6.4 ft.) wide, 0.5 m (1.6 ft.) high and 457.2 mm (18") deep, # 12 sapphire twine, 15.9 mm (5/8 inch) mesh with an inner mesh of 3.2 mm (1/8") delta netting and ¼ inch bar inner cod, mounted on a 2 m (6.4 ft) horizontal bar and two triangular skids.
Mini- Fyke: Design = 1.2 m (4 ft) by 0.6 m (2 ft) rectangular cabs, 0.6 m (2 ft) hoops and 4.5 m (15 ft) by 0.6 m (2 ft) weighted lead. Frames = Two 0.63 cm (1/4 inch) spring steel cabs and hoops. Mesh =3 mm (1/8th inch) coated ace mesh.
Push Trawl: Custom design = 2.4 m (6 ft.) width, 0.61 m (2 ft.) height and 1.8 m (6 ft.) length. Mesh size of 4.0 mm (3/16 inch) with a zippered cod end. Standard trawl doors are used = 19.1 mm (3/4") marine plywood, 762 mm (30") by 381 mm (15") and 12.7 mm (1/2 inch) thick heavy steel runners.
Bag Seine: 9.1 m (30 ft) long by 1.8 m (6 ft) high with a 1.8 m x 1.8 m x 1.8 m bag. Mesh = 6.4 mm (1/8$_{th}$ inch) ace mesh with 29.5 kg (65 lb) lead core line.

Data Collection and Analysis
Little information is known about the life history characteristics of sicklefin chubs. Based on spawning dates, anecdotal information and life history traits of other chub species annuli are thought to be laid down in May (Schemeske 1974). Collection of specimens during fish community season alleviates concerns of collection during annuli formulation. Use of scales for back-calculating lengths is a commonly used approach in determining growth histories of individuals and life history characteristics of populations (Jearld 1983).

Specimens of small bodied target species were preserved in 10% formalin solution with all appropriate information (*i.e*., Date, Field Office, Segment Number, Unique Identifier, Fish ID and Species) recorded for later analysis. Attempts were made to collect ten fish per ten millimeter size class in each segment. In the lab, specimens were prepared for analysis. Approximately 20 scales were removed from rows 2, 3 and 4 above the lateral line at the dorsal fin for all three chub species. Ten cleaned scales were mounted to glass slides and uniquely identified to prevent reader bias. Cyprinid scales from 2004, 2005 and 2006 were processed such that cleaned scales were arranged in vertical columns on left side of slide and excess scales were arranged in a ring on right side of slide. It has been determined that digital capturing of these scales is more efficient when cleaned scales are arranged in vertical columns. New procedures have been developed for more efficient processing and longer storage of scales. Future samples will be processed using an ultrasonic cleaner.

All scales were digitally captured using a Scion Color Digital Camera (770 pixels per mm) attached to a Meiji dissecting scope at 40X magnification. Ages were determined by total number of annuli per scale. Annuli were interpreted by identifying the "crossing over" of one circulus over another (Jerald 1983). To avoid reader bias, each scale was independently analyzed by two readers without knowledge of other reader's age estimation. Scales were read a second time (by both readers) in instances where the assigned age was not in agreement between the two readers. If discrepancies remained between the two ages after the second reading, both readers simultaneously viewed the scale to assign its age.

Measurements for determining radii and annular distances relative to growth data were performed using Image J software. Radii and annular measurements were taken from the focus to the longest anterior edge on all scales. (Marzolf 1955; Jearld 1983). Mean length at age was estimated by back-calculating to the most recent annulus. The relationship between total length and scale radius was used to determine a value for the intercept (*a*) for use in the Fraser-Lee equation:$[L_i = a + ((L_c - a)(S_i/S_c))]$. All back calculations, regressions and intercepts were performed using Fish BC Fisheries Research Software Version 2.0.

When sturgeon chub data was not normally distributed, all data were $\log_{10}+1$ transformed. A parametric ANOVA with a Tukey's post hoc test ($\alpha = 0.05$) was used to test for significant differences between segments. Probabilities of age at length were calculated for each segment. Probabilities were condensed into age/length keys by segment (Tables 13 – 24). Length frequency distributions were compiled using total catch data for each segment and year (Appendix B). Age frequencies were determined for each segment and year using known age fish data (Appendix C).

Table 1. Segment information for the Missouri River.

Segment Number	Segment Description	Upper River Mile	Lower River Mile	Length (mi)
1	Fort Peck Dam to the confluence of the Milk River	1771.5	1760.0	11.5
2	Confluence of the Milk River to Wolf Point	1760.0	1701.0	59.0
3	Wolf Point to the confluence of the Yellowstone River	1701.0	1582.0	119.0
4	Confluence of the Yellowstone River to the headwaters of Lake Sakakawea	1582.0	1568.0	14.0
5	Fort Randall Dam to the confluence of the Niobrara River	880.0	845.0	35.0
6	Confluence of the Niobrara River to the headwaters of Lewis and Clark Lake	845.0	825.0	20.0
7	Gavins Point Dam to Lower Ponca Bend	811.0	750.0	61.0
8	Lower Ponca Bend to the confluence of the Platte River	750.0	595.0	155.0
9	Confluence of the Platte River to the confluence of the Kansas River	595.0	367.5	227.5
10	Confluence of the Kansas River to the confluence of the Grand River	367.5	250.0	117.5
13	Confluence of the Grand River to the confluence of the Osage River	250.0	130.0	120.0
14	Confluence of the Osage River to the confluence with the Mississippi River	130.0	0.0	130.0

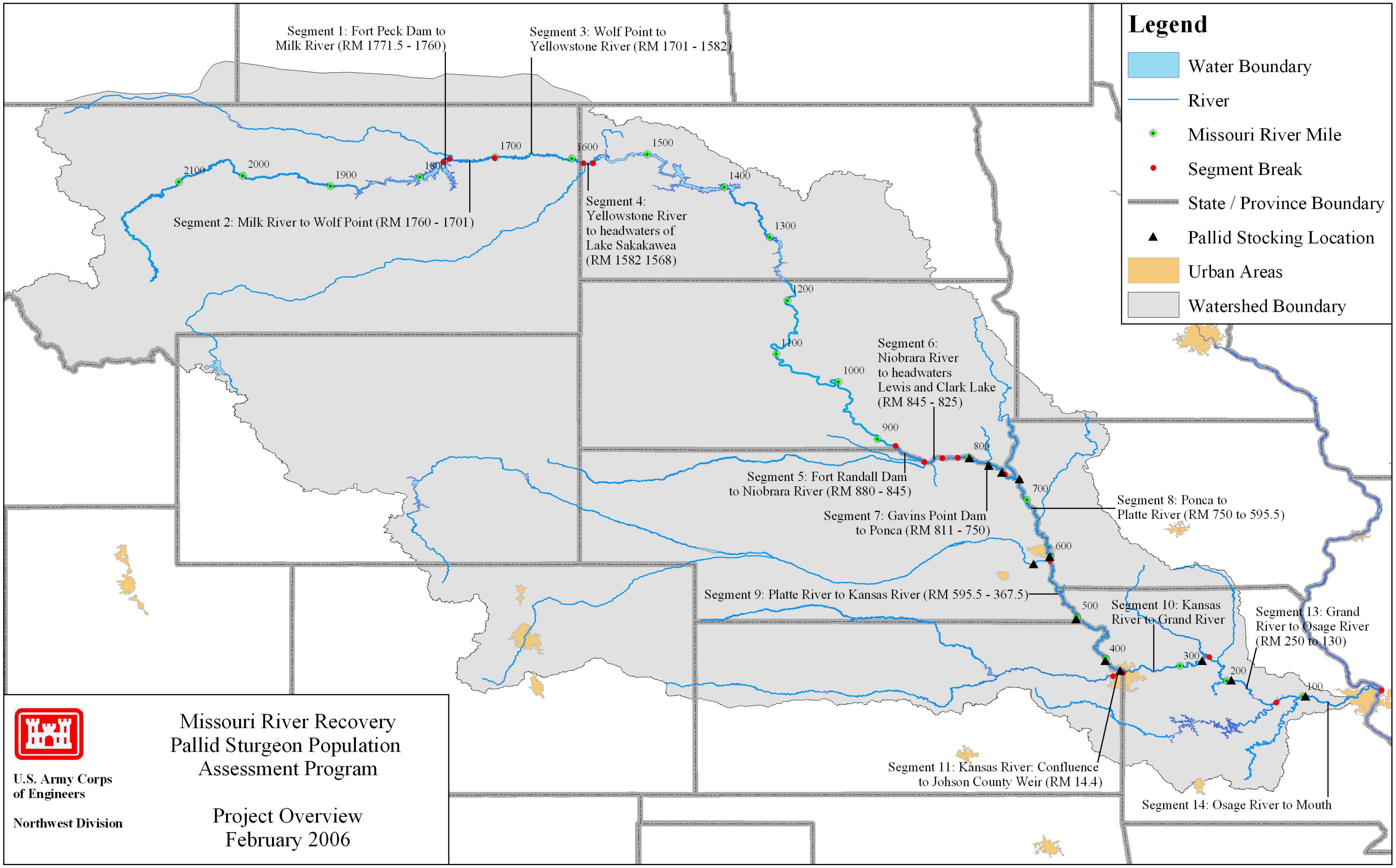


Figure 1. Map of the Missouri River basin with locations of major tributaries and urban areas. Study segments are numbered, labeled and delimited by red dots.

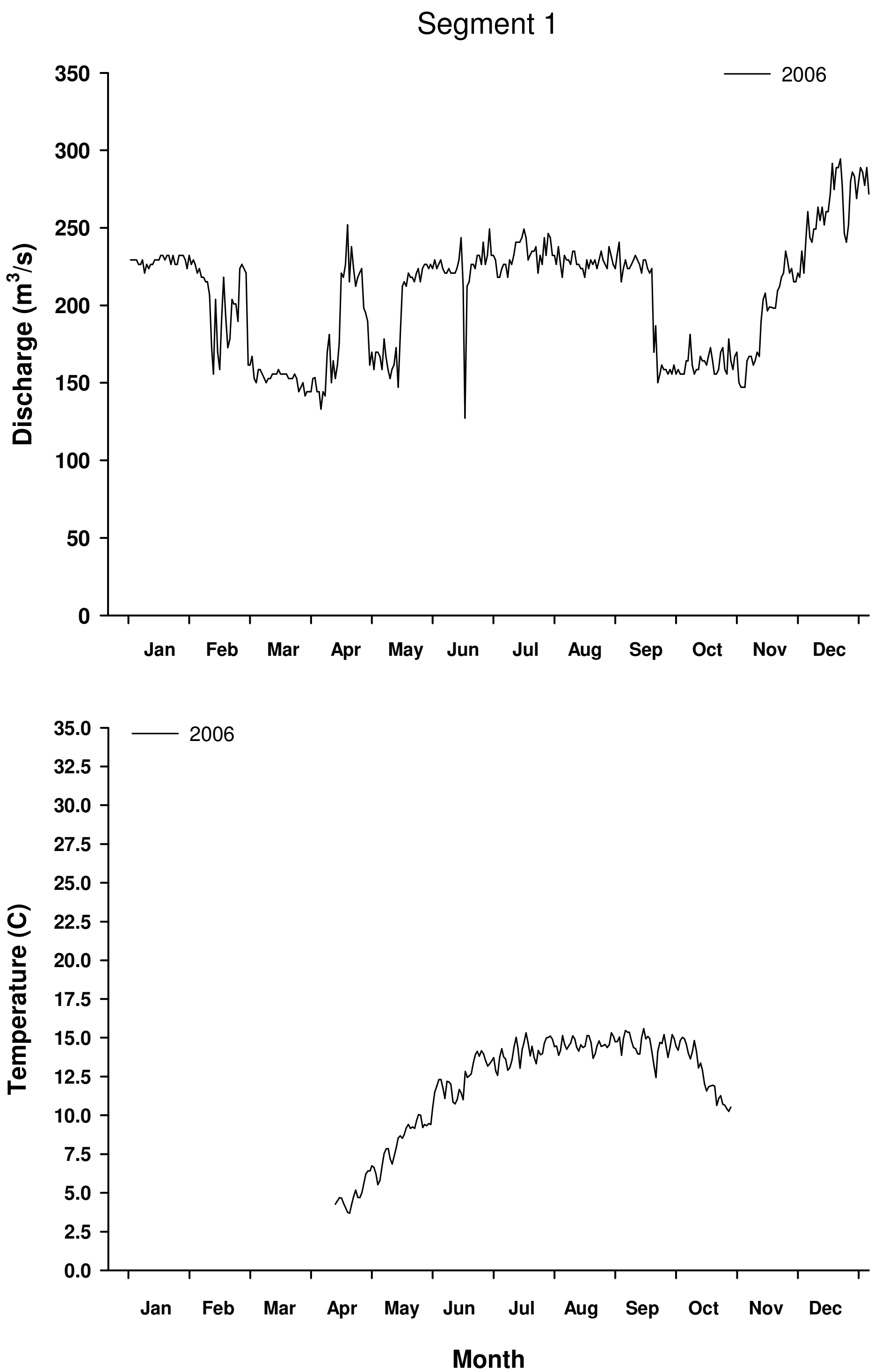


Figure 2. Mean daily discharge and mean daily water temperature for segment 1 of the Missouri River during 2006

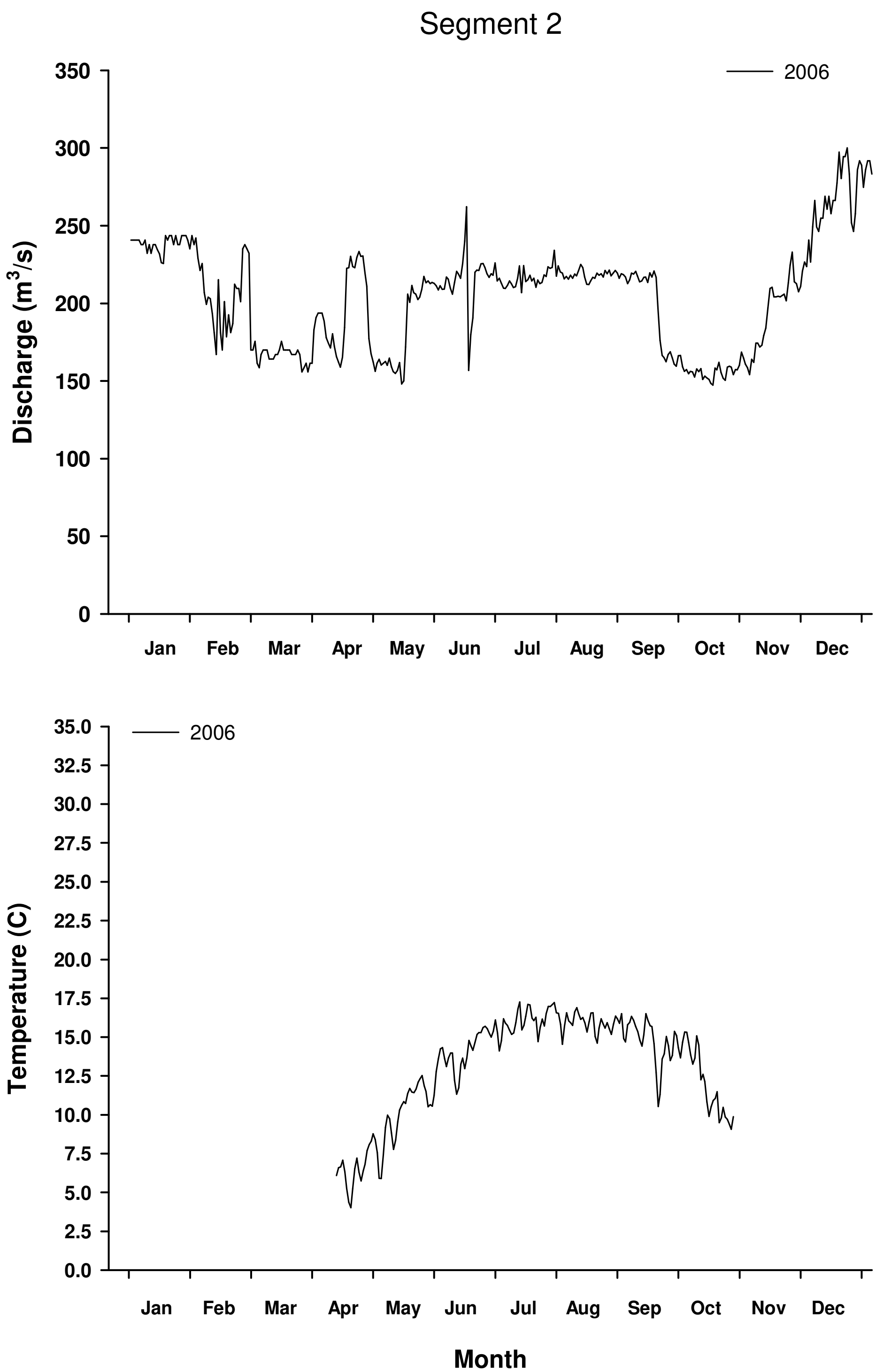


Figure 3. Mean daily discharge and mean daily water temperature for segment 2 of the Missouri River during 2006

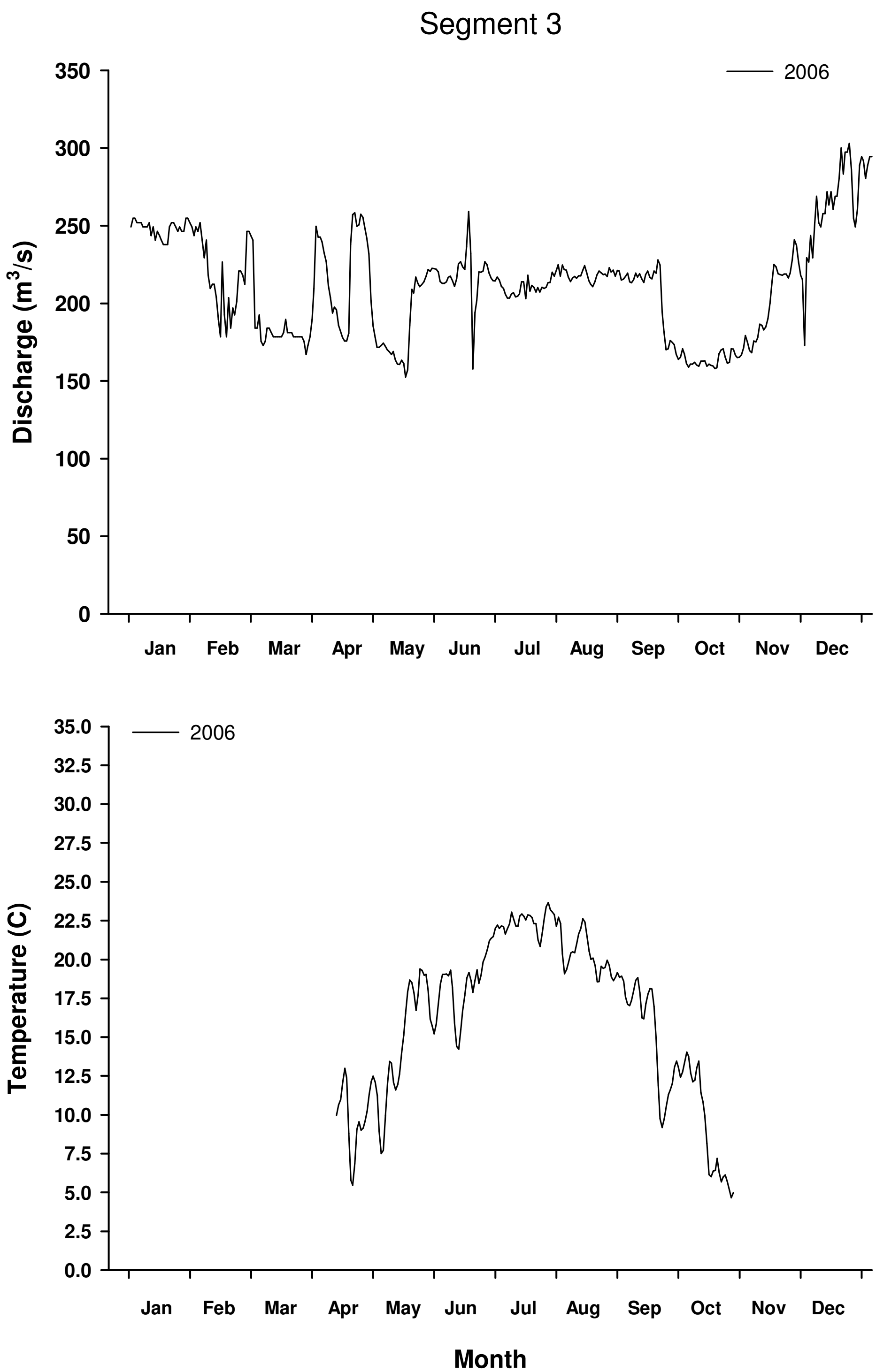


Figure 4. Mean daily discharge and mean daily water temperature for segment 3 of the Missouri River during 2006

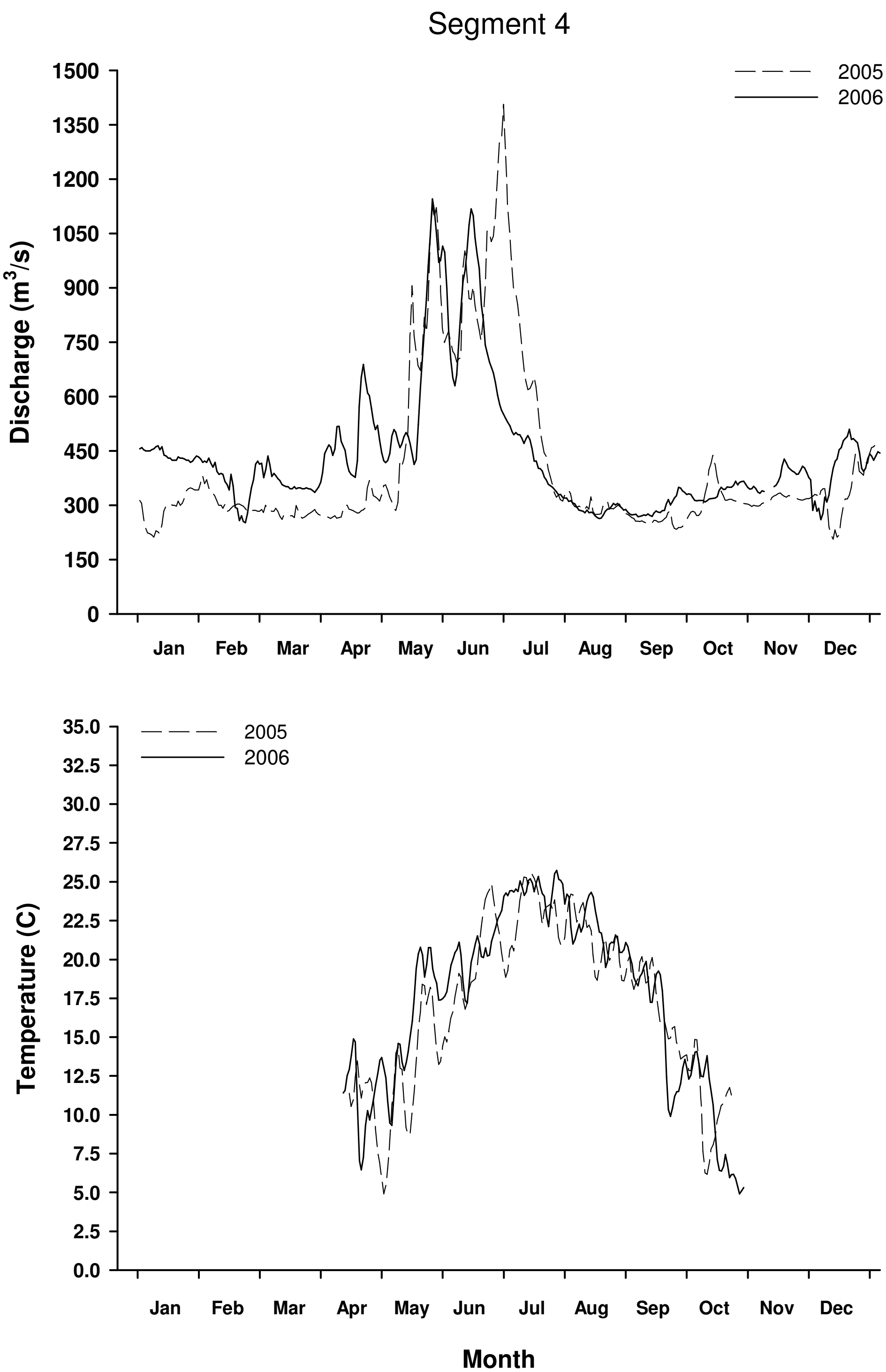


Figure 5. Mean daily discharge and mean daily water temperature for segment 4 of the Missouri River during 2005 and 2006.

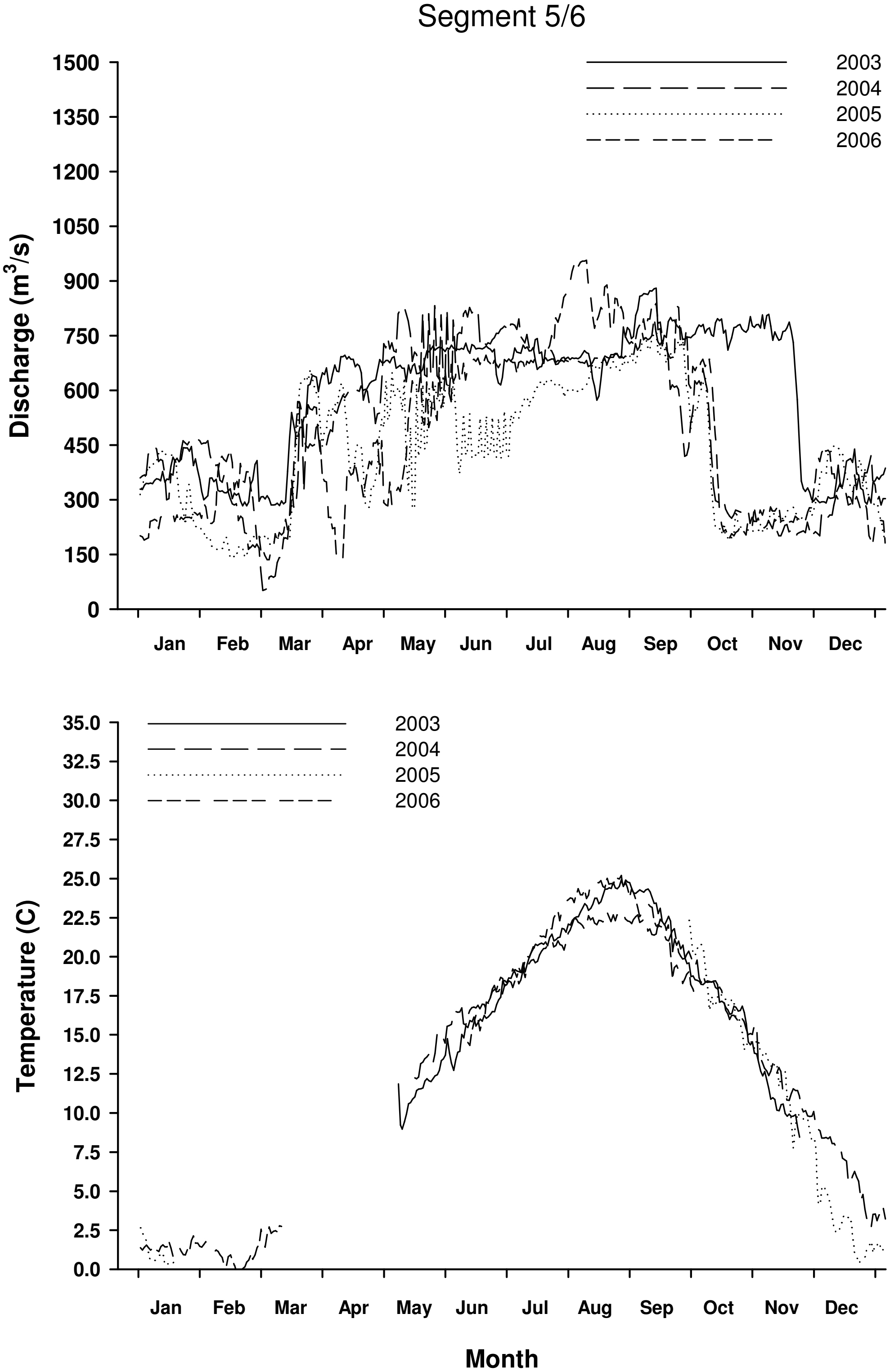


Figure 6. Mean daily discharge and mean daily water temperature for segment 5/6 of the Missouri River during 2003 through 2006.

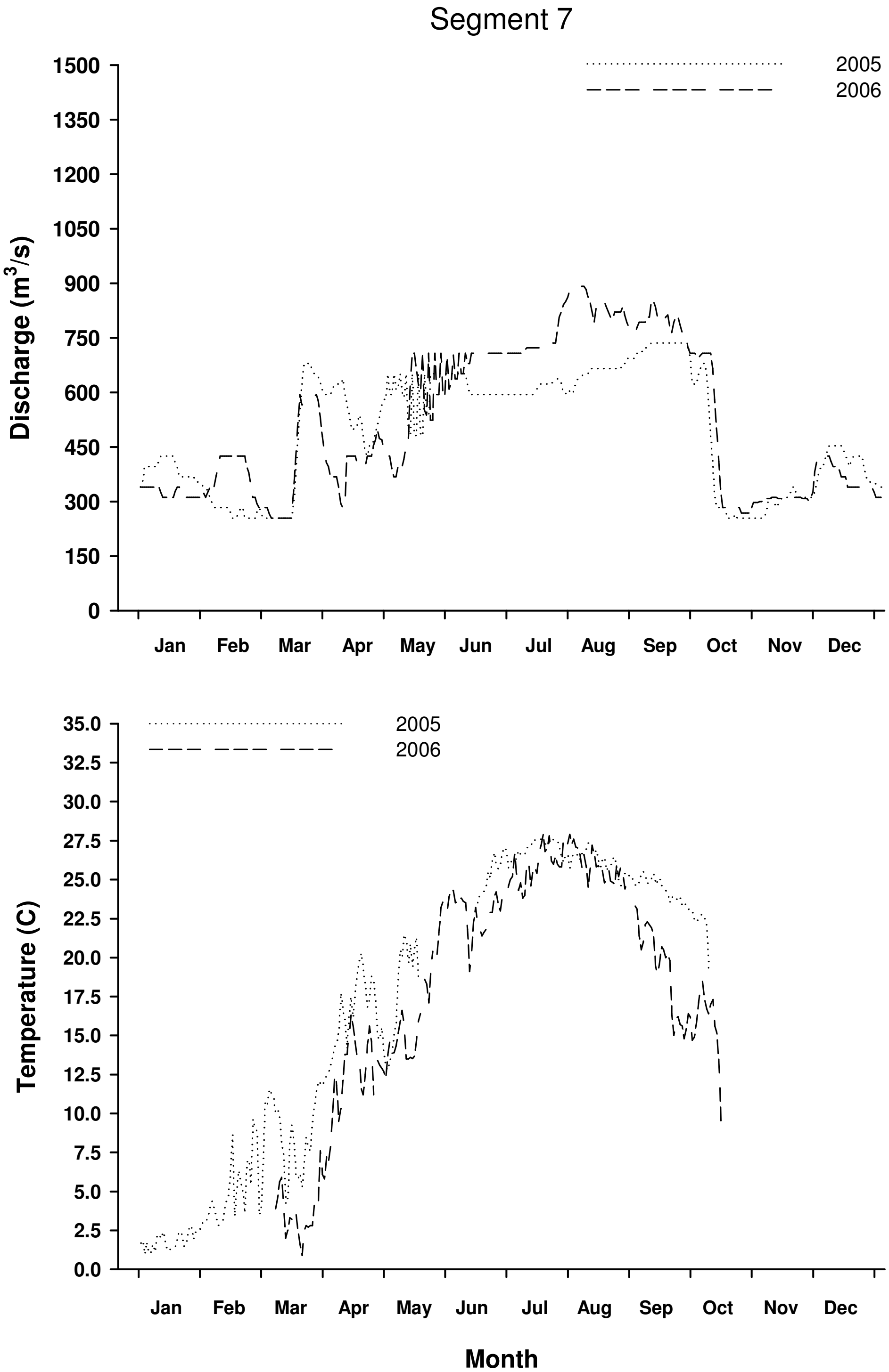


Figure 7. Mean daily discharge and mean daily water temperature for segment 7 of the Missouri River during 2005 and 2006.

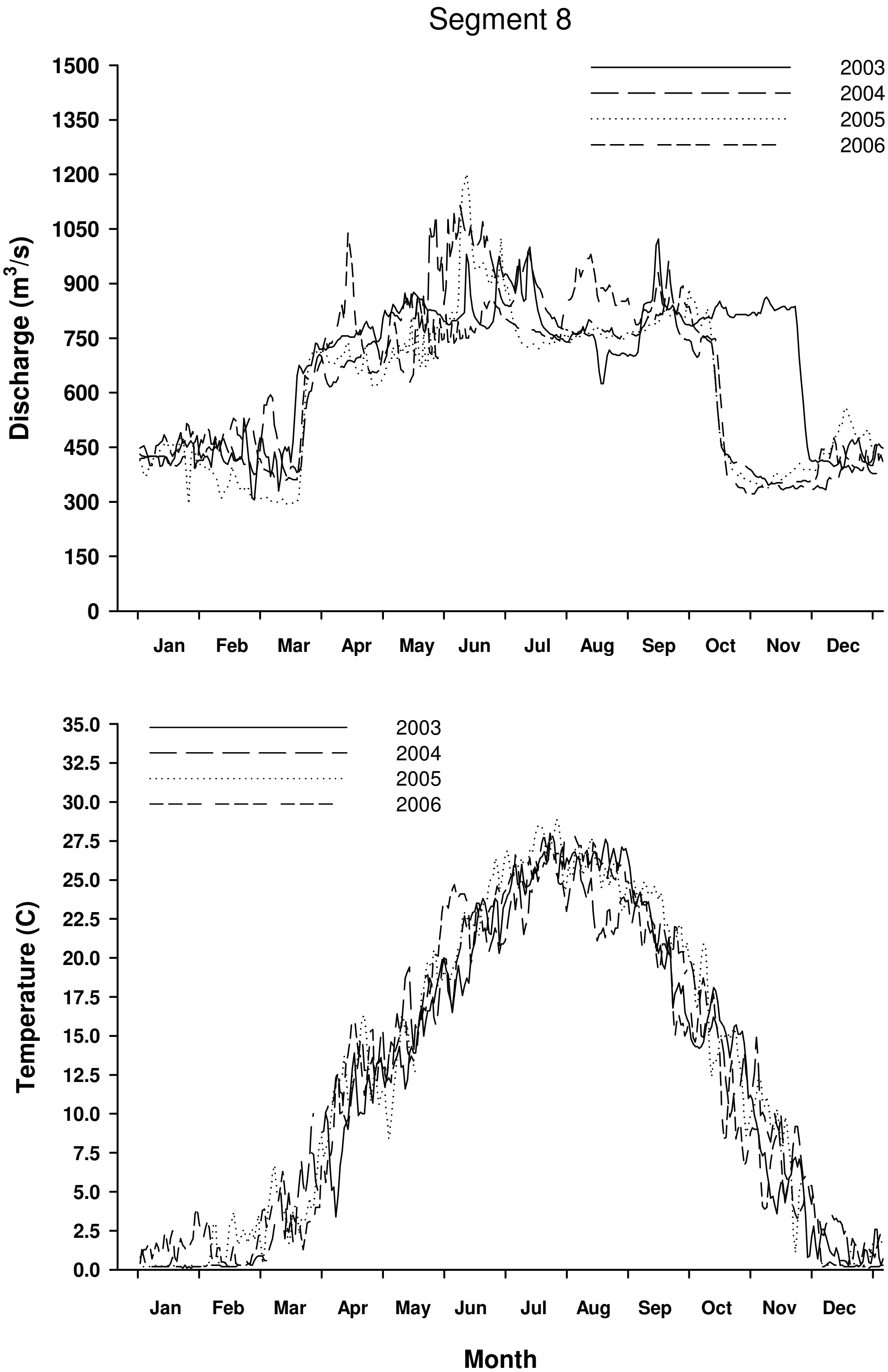


Figure 8. Mean daily discharge and mean daily water temperature for segment 8 of the Missouri River during 2003 through 2006.

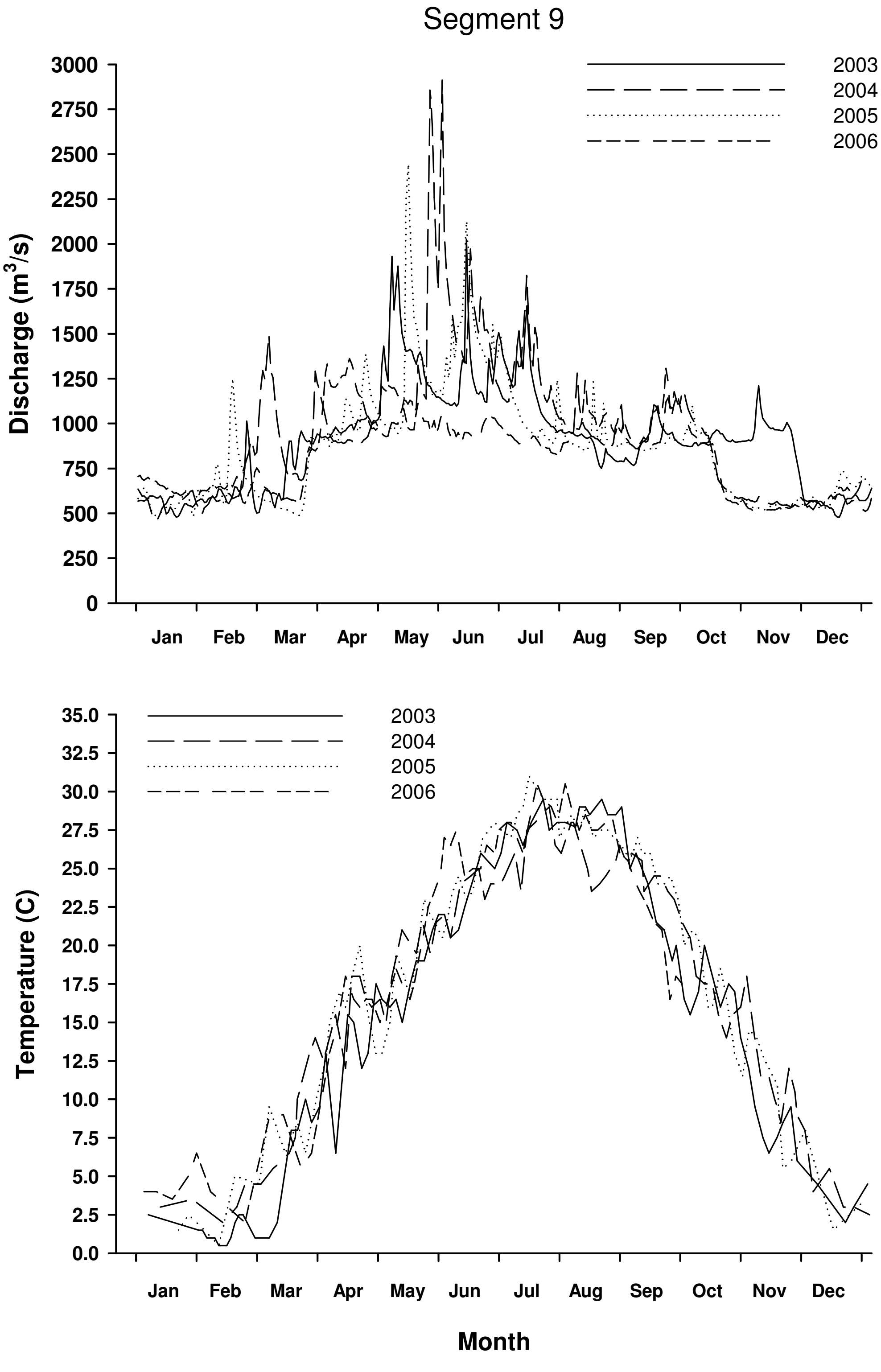


Figure 9. Mean daily discharge and mean daily water temperature for segment 9 of the Missouri River during 2003 through 2006.

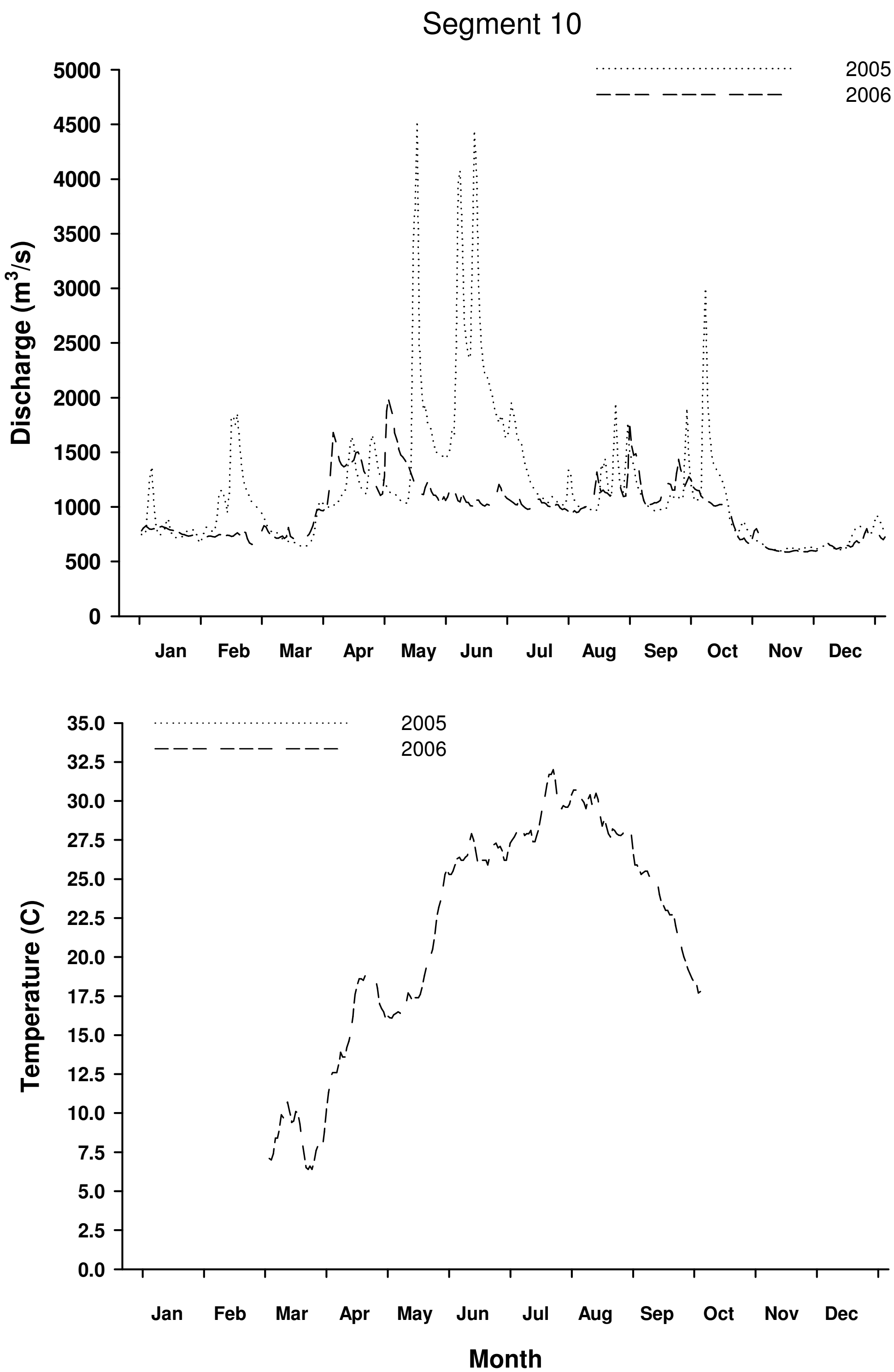


Figure 10. Mean daily discharge and mean daily water temperature for segment 10 of the Missouri River during 2005 and 2006.

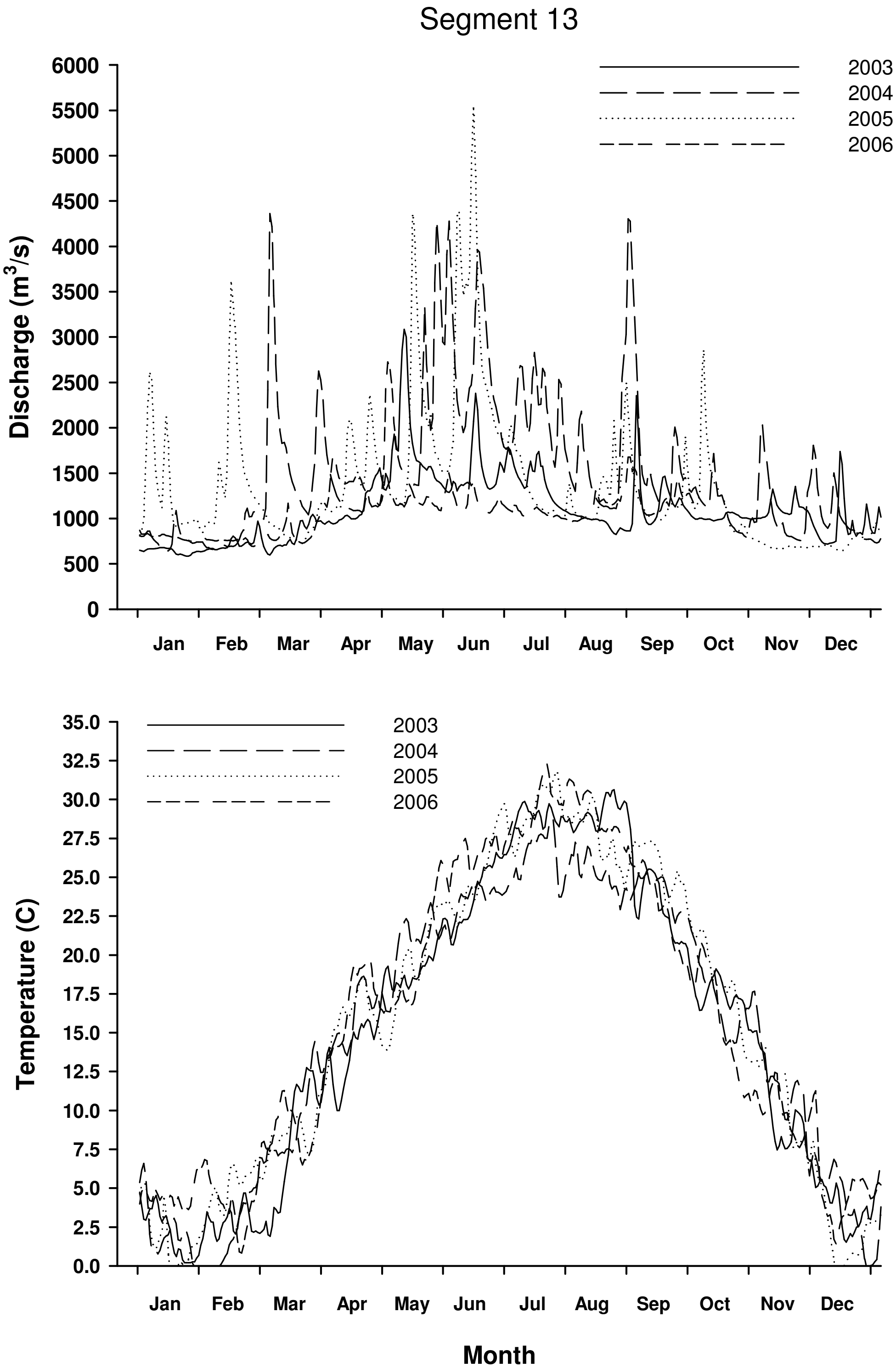


Figure 11. Mean daily discharge and mean daily water temperature for segment 13 of the Missouri River during 2003 through 2006.

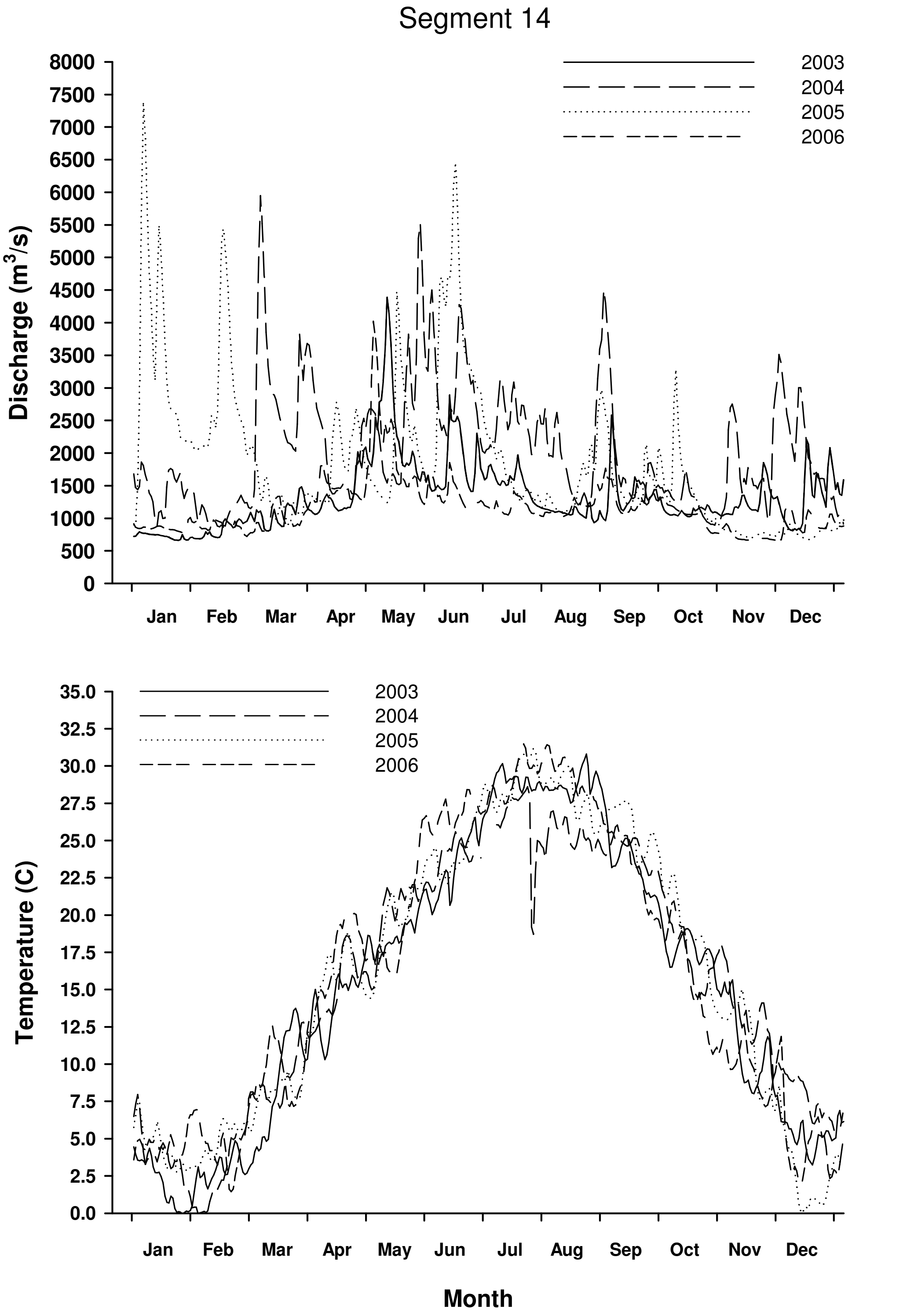


Figure 12. Mean daily discharge and mean daily water temperature for segment 14 of the Missouri River during 2003 through 2006.

Table 2. Starting and ending date by year when aging structures sicklefin chubs were collected.

Year	Starting Date	Ending Date	Segments
2004	July 2004	October 2004	9, 13 and 14
2005	July 2005	October 2005	4, 8, 9, 10, 13 and 14
2006	July 2006	October 2006	3, 4, 7, 8, 9, 10, 13 and 14

Results

Mean daily discharge data and mean daily temperature data showed a general increase in flows and a greater fluctuation in temperature ranges from upstream to downstream (Figures 2 – 12).

Aging structures were collected from 574 sicklefin chubs captured during 2004, 2005, and 2006 (Table 3). The intercept value (size when scales begin to develop) for sicklefin chubs collected in this program, was 19.4 mm (Appendix A). In 2004, aging structures were collected from segments 13 and 14. Mean back calculated lengths-at-last annulus for 2004 were 31 mm at age 1, 49 mm at age 2 and 65 mm at age 3 (Table 5, Figure 14). One sicklefin chub (back calculated length-at-last annulus = 83 mm) was determined to be age 4 from segment 13. In 2005, aging structures were collected from segments 4, 8, 9, 10, 13 and 14. Mean back calculated lengths-at-last annulus for 2005 were 33 mm for age 1, 60 mm for age 2 and 82 mm for age 3 (Table 6, Figure 15). Sicklefin chub aging structures were collected from segments 3, 4, 7, 8, 9, 10, 13 and 14 in 2006. Mean back calculated lengths-at-last annulus for 2006 were 30 mm for age 1, 58 mm for age 2 and 77 mm for age 3 (Table 7, Figure 16).

Mean back calculated total length-at-last annulus for all years combined showed faster growth in upper-most segments. In general sicklefin chubs in the upper segments were longer at age 1 and 2 than the lower segments. However, by age 3 fish in all segments averaged similar lengths (Figure 17).

A comparison of upper and lower universe for 2005 and 2006 showed mixed results (Figure 18). Upper and lower universe fish were similar in 2005 while upper universe fish were longer at all three ages in 2006. There were no upper universe samples to compare for 2004 but the lower universe samples were similar to 2005 and 2006.

In 2004, age zero and two year old sicklefin chubs had significantly larger mean-length-at-capture rates in segment 13 than in segment 14 (Table 9). One year old sicklefin chubs were larger in segment 4 than in all other segments in 2005 (Table 10). Age two sicklefin chubs were larger in segment 8 than in segments 4, 13 and 14; but were similar to segments 9 and 10 (Table 10). There were no significant differences in the age three fish in 2005 (Table 10). In 2006, one year old fish were larger in segment 4 than in segments 9 and 13 (Table 11). Age 2 fish were larger in segment 7 than in segments 4, 10, 13 and 14 (Table 11). No significant differences were found between segments for age three fish in 2006 (Table 11). One and two year old sicklefin chubs were larger in the upper universe, while three year old fish were similar in size (Table 12).

Length frequency distributions were compiled using total catch data for each segment and year (Appendix B). Length frequency distributions for all sicklefin chub captures were compared between segments for each year and showed noticeable trends of size and age classes (Appendix B). Most sicklefin chubs captured fell between 30 mm and 60 mm size range. The data suggest that recruitment in and survivorship of the 2004 year class to be high. In 2004, most fish captured were in the 30 mm size class. In 2005, most were captured in the 40 mm size class and by 2006 most captures were 50 mm or larger. Overall sicklefin chub catch rates decreased with time. Segment 14 had the highest catch rate of sickelfin. Segments 8 and 10 showed relatively low capture rates compared to the other segments.

Age frequencies were compiled for each year and segment (Appendix C). In 2004, 12% of the catch were age 0 sicklefin chubs, 30% were age 1, 41% were age 2, 16% were age 3 and 1% were age 4. In 2005, 0.5% were age 0, 49% were age 1, 32% were age 2 and 19% were age 3. In 2006, 27% were age 1, 65% were age 2 and 8% were age 3. The Y-intercept for back-calculated sicklefin chub growth based on regression analysis range from 2.4 to 25.1 (Appendix A).

Table 3. Total number of sicklefin chubs collected for age and growth analysis.

Length	Overall Total	2004				2005							2006								
		9	13	14	Total	4	8	9	10	13	14	Total	3	4	7	8	9	10	13	14	Total
20	9	0	2	6	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	32	0	12	3	15	0	0	1	0	0	0	1	0	0	0	0	2	0	0	0	2
40	85	2	10	15	27	0	0	3	3	7	2	15	0	0	0	0	10	5	10	0	25
50	87	0	10	15	25	1	0	3	13	8	8	33	0	0	0	0	12	8	4	0	24
60	99	0	16	15	31	3	0	5	9	11	10	38	0	1	0	0	11	7	10	1	30
70	94	0	7	12	19	11	0	5	10	4	8	38	2	10	0	0	9	2	10	9	42
80	77	1	4	4	9	12	1	1	10	9	0	33	10	10	0	1	7	6	10	1	45
90	65	0	2	2	4	0	4	4	9	5	1	23	10	6	0	1	6	1	10	0	34
100	21	0	0	0	0	0	13	5	7	1	1	27	8	0	2	0	2	0	1	0	13
110	5	0	0	0	0	0	1	5	2	0	0	8	0	0	1	0	2	0	0	0	3
120	0	0	0	0	0	0	0	1	1	0	0	2	0	0	0	0	0	0	0	0	0
Total	574	3	63	72	138	27	19	33	64	45	30	218	30	27	3	2	61	29	55	11	218

Table 5. Mean back-calculated total length-at-last annulus (+/- 2 SE) of sicklefin chubs collected in each segment during 2004.

Age	Segments 13	Segments 14	Mean
1	32 (2.502)	29 (2.132)	30.81 (1.73)
2	52 (2.642)	46 (2.184)	48.59 (1.84)
3	58 (6.512)	64 (2.440)	65.11 (2.54)
4	83 (0)		83.0 (0)

Table 6. Mean back-calculated total length-at-last annulus (+/- 2 SE) of sicklefin chubs collected in each segment during 2005.

Age	Segments							Mean
	4	7	8	9	10	13	14	
1	35		0	31	31	34	34	32.79
	(3.5)		(0)	(2.94)	(2.12)	(2.34)	(2.38)	(1.17)
2	56		68	67	60	62	54	59.94
	(2.18)		(3.82)	(8.46)	(3.44)	(2.86)	(5.3)	(0.91)
3			82	84	82	78	88	82.23
			(2.54)	(2.98)	(4.38)	(4.26)	(0)	(0.90)

Table 7. Mean back-calculated total length-at-last annulus (+/- 2 SE) of sicklefin chubs collected in each segment during 2006.

Age	**Segments**								**Mean**
	3	**4**	**7**	**8**	**9**	**10**	**13**	**14**	
1	0	44	0	0	28	30	27	37	29.61
	(0)	(1.02)	(0)	(0)	(3.9)	(2.3)	(2.46)	(0)	(1.82)
2	62	60	69	64	62	54	56	53	58.42
	(2.44)	(3.5)	(0)	(2.8)	(2.46)	(4.58)	(2.6)	(2.9)	(1.41)
3	75	72	74	0	86	0	70	0	77.36
	(5.86)	(8.88)	(3.14)	(0)	(7.34)	(0)	(0)	(0)	(4.29)

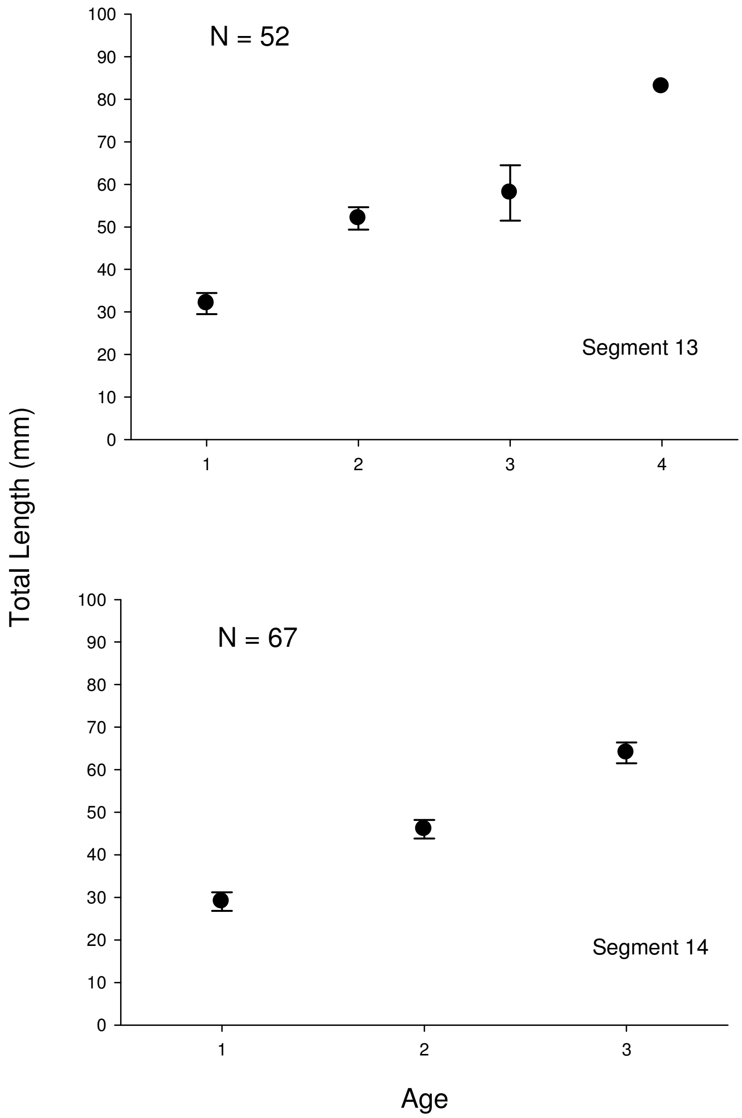


Figure 14. Mean back-calculated total length-at-last annulus of sicklefin chubs collected for age and growth analysis from segments 13 and 14 of the Missouri River during 2004.

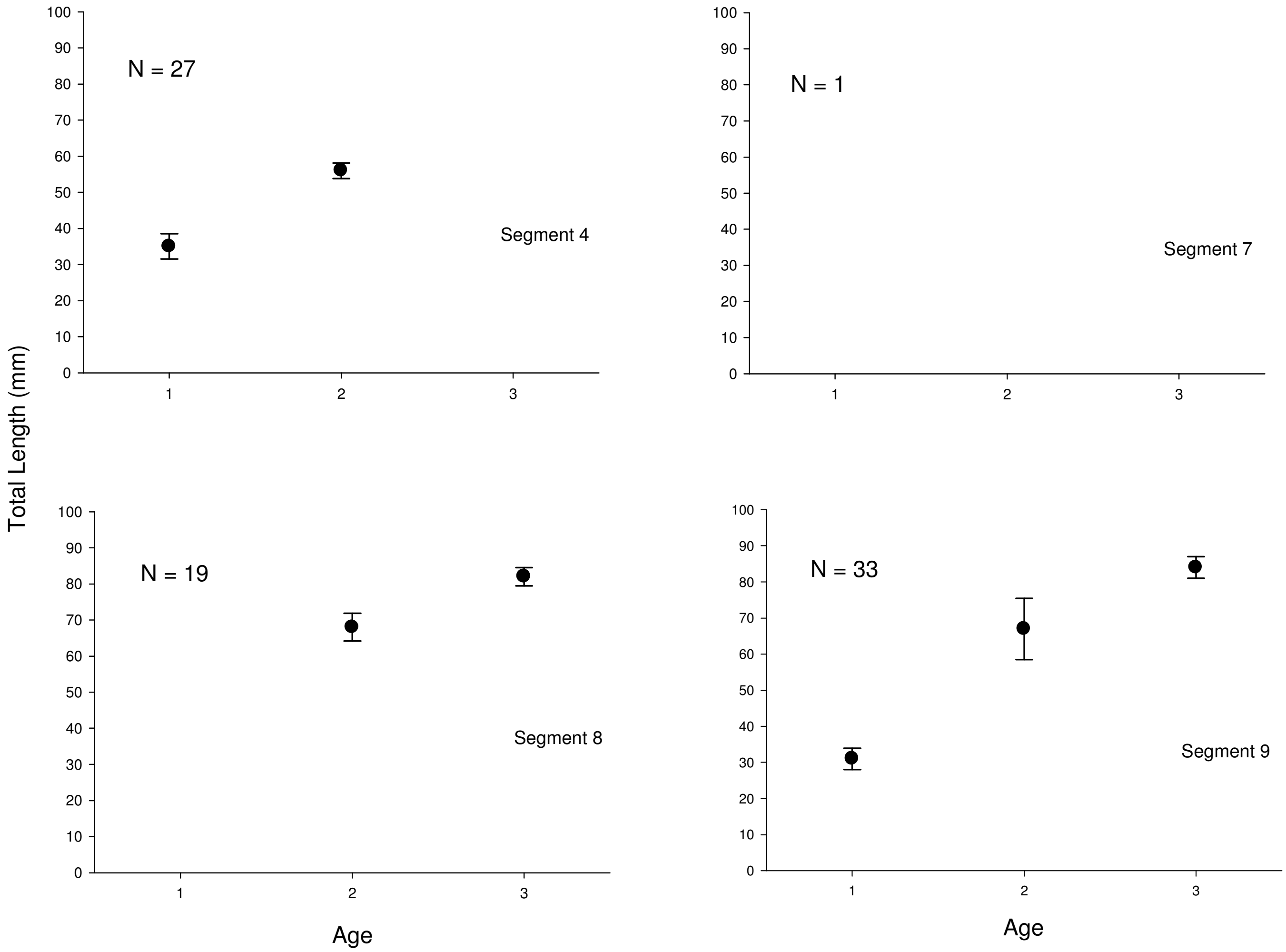


Figure 15. Mean back-calculated total length-at-last annulus of sicklefin chubs collected for age and growth analysis from segments 4, 7, 8, 9, 10, 13 and 14 of the Missouri River during 2005.

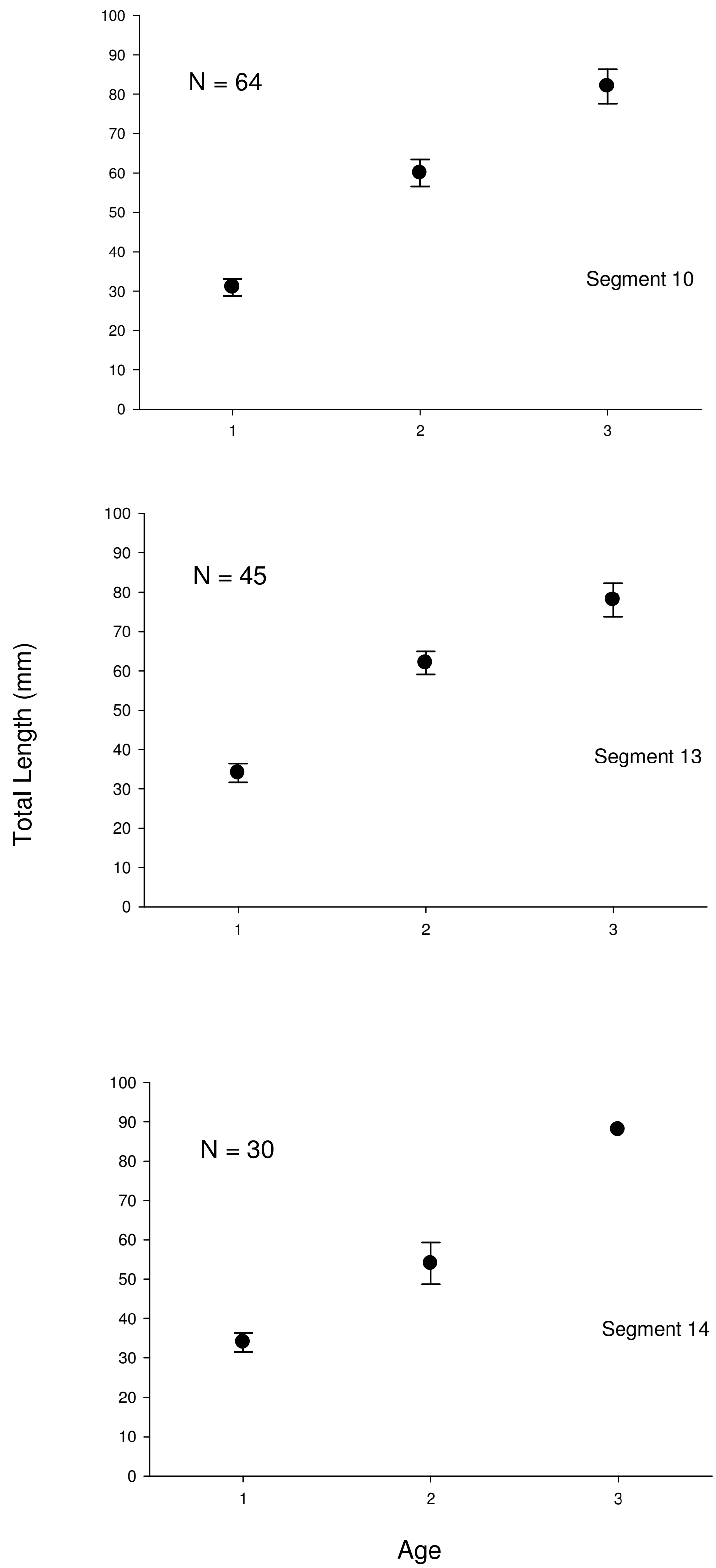


Figure 15. Continued.

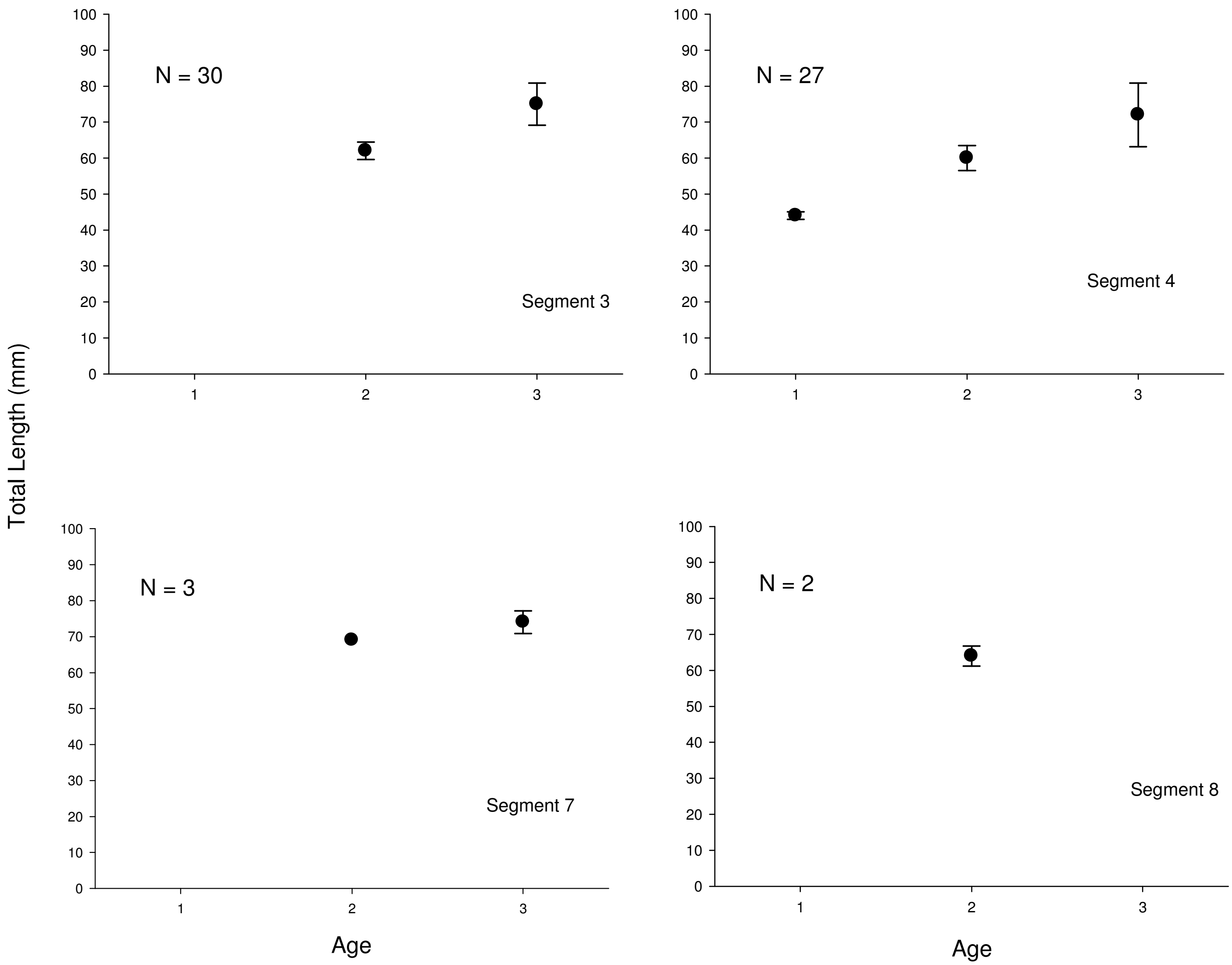


Figure 16. Mean back-calculated total length-at-last annulus of sicklefin chubs collected for age and growth analysis from segments 3, 4, 7, 8, 9, 10, 13 and 14 of the Missouri River during 2006.

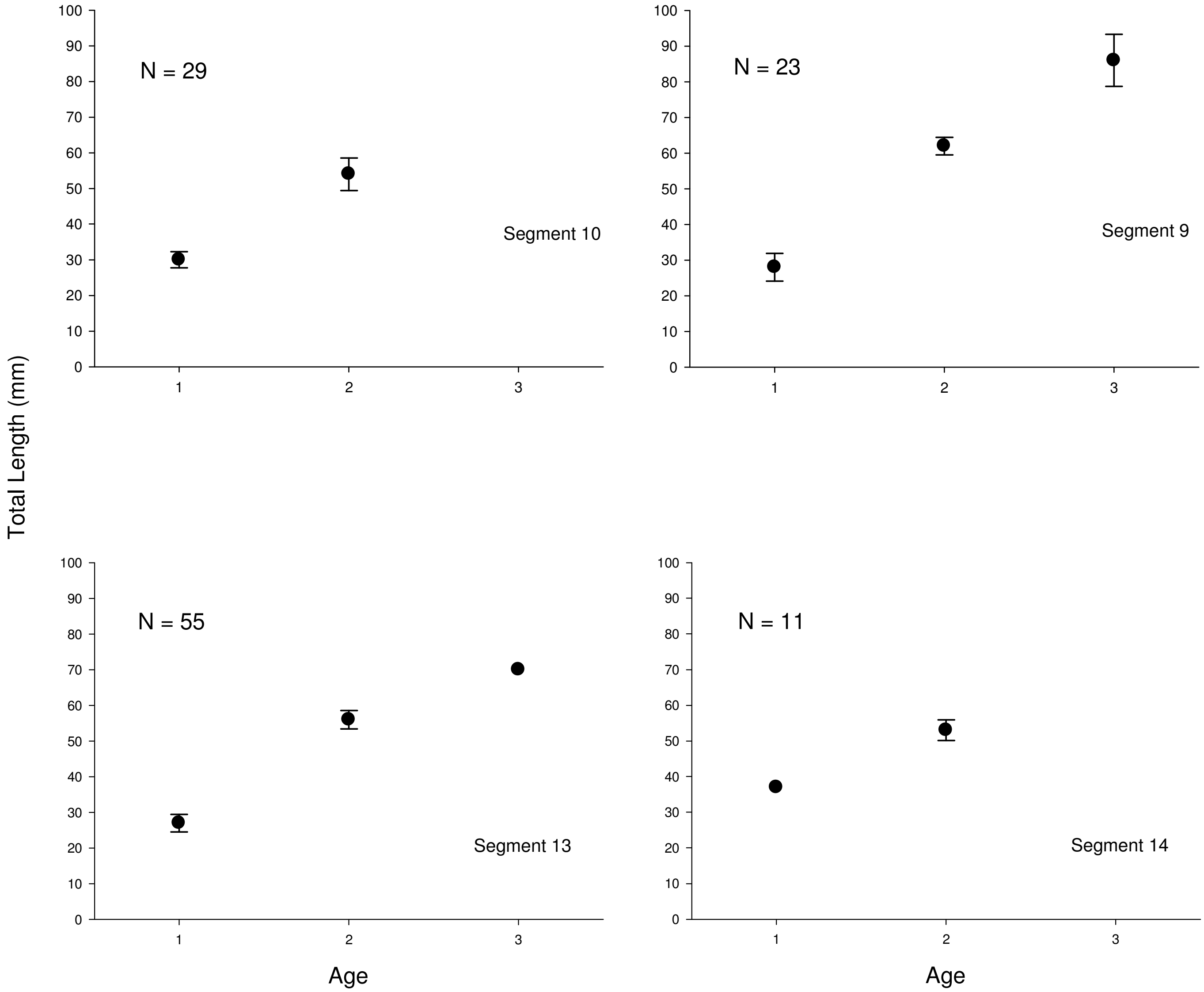


Figure 16. Continued.

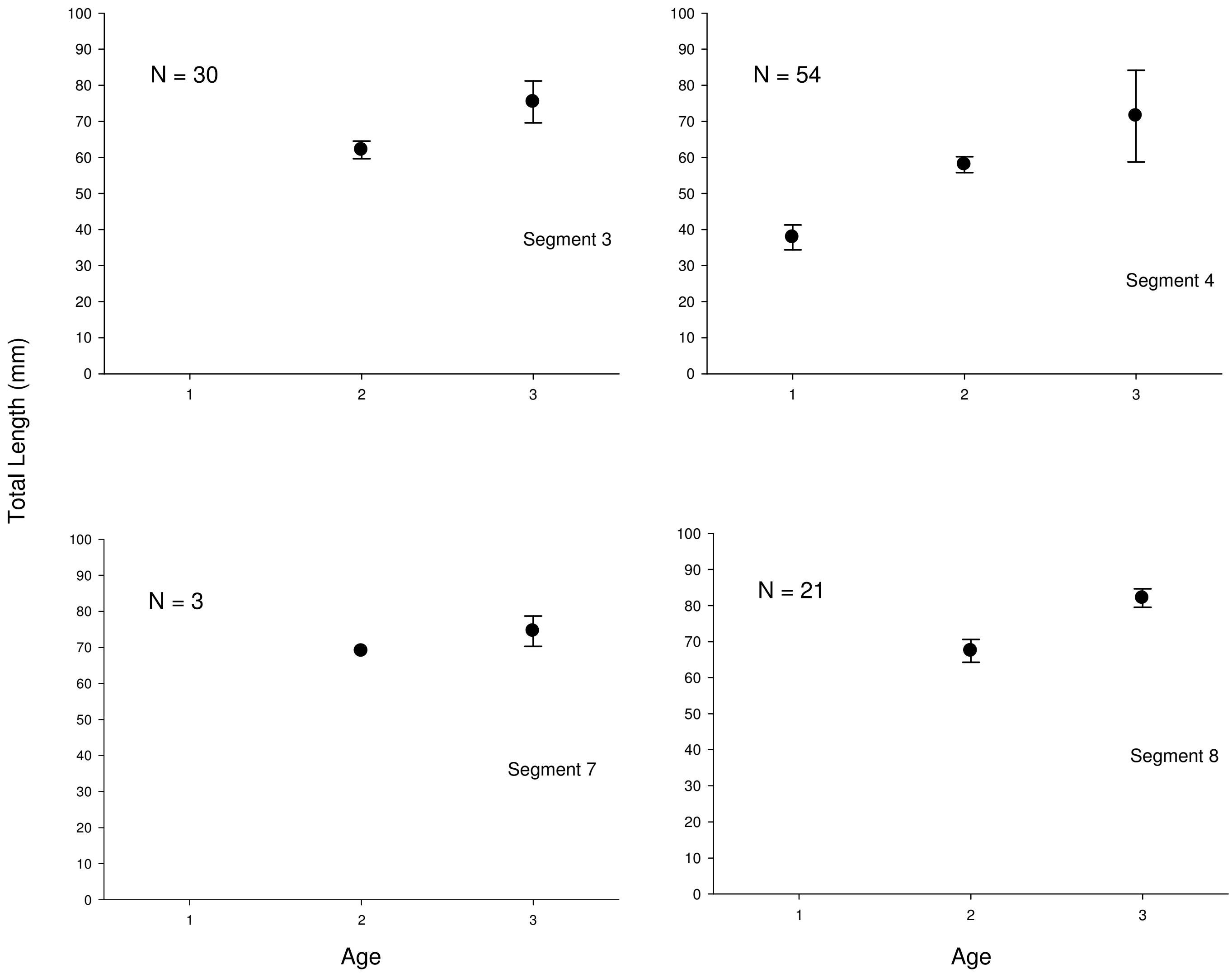


Figure 17. Mean back-calculated total length-at-last annulus of sicklefin chubs that were collected for age and growth analysis from segments 3, 4, 7, 8, 9, 10, 13 and 14 of the Missouri River for all years combined.

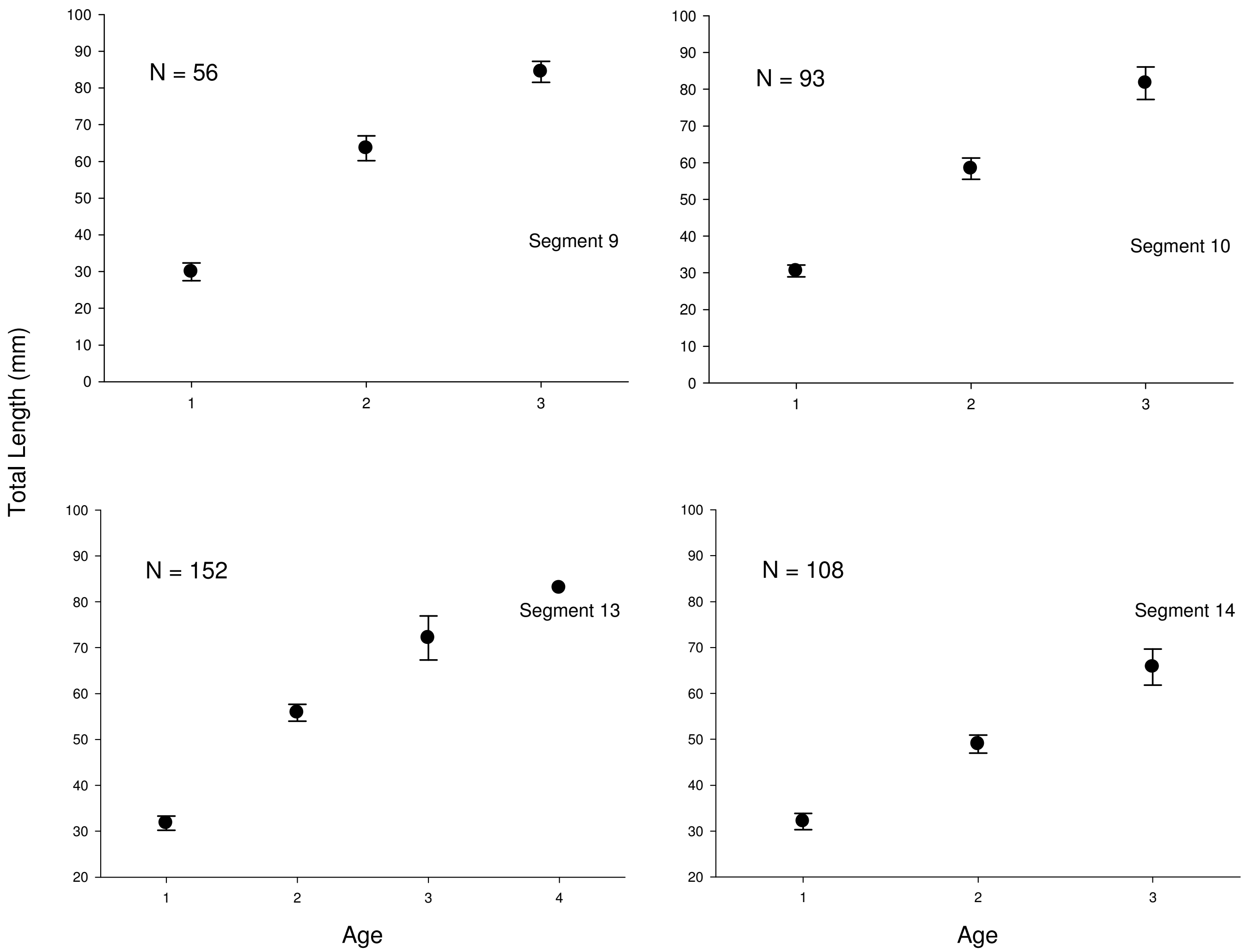


Figure 17. Continued.

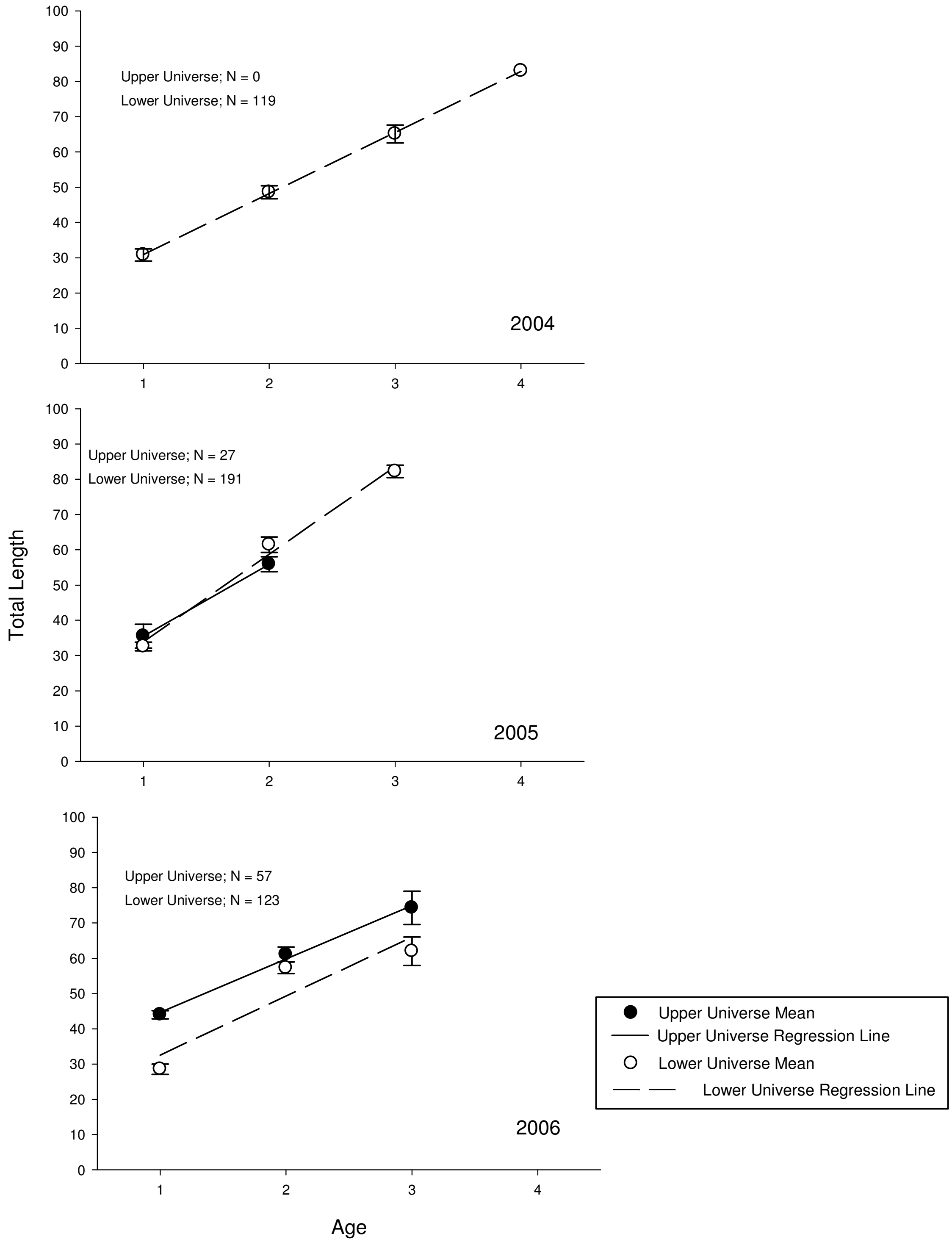


Figure 18. Mean back-calculated total length-at-last annulus of sicklefin chubs collected for age and growth analysis from the upper and lower universe of the Missouri River for 2004, 2005 and 2006. A best fit regression line was used to show trends in growth for each universe.

Table 9. Mean length-at-capture comparisons of sicklefin chubs between segments for 2004. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05).

Age	**Segment**											
	1	**2**	**3**	**4**	**5/6**	**7**	**8**	**9**	**10**	**11**	**13**	**14**
0*											34.9 a (4.1; 7)	27.9 b (2.4; 7)
1*											50.1 a (3.9; 19)	46.6 a (3.3; 17)
2*											68.1 a (3.4; 20)	61.8 b (2.7; 29)
3*											81.4 a (6.9; 5)	79.7 a (3.4; 14)
4											96.0 -	

Table 10. Mean length-at-capture comparisons of sicklefin chubs between segments for 2005. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05).

Age	Segment											
	1	**2**	**3**	**4**	**5/6**	**7**	**8**	**9**	**10**	**11**	**13**	**14**
0*								28.0				
								-				
1*				62.5 a				51.3 b	51.4 b		47.9 b	51.0 b
				(7.0; 8)				(5.9; 15)	(3.2; 32)		(3.3; 29)	(3.6; 23)
2*				70.4 cd			87.0 a	85.6 ab	76.3 abc		75.3 bc	63.9 d
				(2.4; 19)			(4.3; 7)	(12.7; 5)	(3.7; 21)		(3.2; 12)	(6.9; 7)
3*						97a	95.5 a	97.7a	96.2a		86 a	95 a
						-	(2.2;12)	(3.9;12)	(5.6;11)		(4.2; 4)	-

Table 11. Mean length-at-capture comparisons of sicklefin chubs between segments for 2006. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05).

Age	Segment											
	1	2	3	4	5/6	7	8	9	10	11	13	14
1*				65.7 a				40.4 b	50.0 ab		40.0 b	59.0 ab
				(2.3; 3)				(4.1; 9)	(3.9; 19)		(4.0; 17)	-
2*			79.8 ab	72.7 b		96.0 a	81.5 ab	77.7 ab	70.7 b		70.6 b	64.4 b
			(3.2; 25)	(3.8; 22)		-	(4.9; 2)	(3.1; 10)	(5.3; 10)		(3.3; 37)	(4.5; 10)
3*			92.6 a	81 a		97.5 a		99.5 a			90.0 a	
			(1.9; 5)	(11.8; 2)		(12.7; 2)		(6.8; 4)			-	

Table 12. Mean length-at-capture comparisons of sicklefin chubs between the upper and lower sampling universe. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Sampling universe comparisons were done with a t-test. Sharing a letter indicate no significant differences while different letters indicate significance differences (alpha = 0.05).

Age	Sampling Universe	
	Upper	**Lower**
0		31.1 (2.8; 15)
1*	63.4 a (5.1; 11)	48.1 b (1.4; 181)
2*	74.7 a (2.1; 66)	71.0 b (1.6; 171)
3*	89.3 a (5.1; 7)	91.3 a (2.4; 67)
4		96.0 -

Table 13. Age/length key for segment 1. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age		
	1	2	3
10			
20			
30			
40	No data available for Segment 1		
50			
60			
70			
80			
90			
100			
110			
Total Number	N = 0		
Sample Years			

Table 14. Age/length key for segment 2. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age		
	1	2	3
10			
20			
30			
40	**No data available for Segment 2**		
50			
60			
70			
80			
90			
100			
110			
Total Number	N = 0		
Sample Years			

Table 15. Age/length key for segment 3. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 1	Age 2	Age 3
10			
20			
30			
40			
50			
60		100	
70		100	
80		100	
90		37.5	62.5
100			
110			
Total Number	N = 30		
Sample Years	2006		

Table 16. Age/length key for segment 4. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**		
	1	**2**	**3**
10			
20			
30			
40	100		
50	50	50	
60	23.8	76.2	
70	13.6	81.8	4.5
80		83.3	16.7
90			
100			
110			
Total Number	N = 54		
Sample Years	2005, 2006		

Table 17. Age/length key for Segments 5/6. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**		
	1	**2**	**3**
10			
20			
30			
40		**No data available for Segments 5/6**	
50			
60			
70			
80			
90			
100			
110			
Total Number	N = 0		
Sample Years	0		

Table 18. Age/length key for segment 7. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**		
	1	**2**	**3**
10			
20			
30			
40			
50			
60			
70			
80			
90		33.3	66.7
100			100
110			
Total Number	N = 4		
Sample Years	2005, 2006		

Table 19. Age/length key for segment 8. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age		
	1	2	3
10			
20			
30			
40			
50			
60			
70		100	
80		100	
90		15.4	84.6
100			100
110			
Total Number	N = 21		
Sample Years	2005, 2006		

Table 20. Age/length key for segment 9. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age		
	1	2	3
10			
20	100		
30	100		
40	100		
50	100		
60	66.7	33.3	
70		100	
80		75	25
90		12.5	87.5
100			100
110			
Total Number	N = 55		
Sample Years	2005, 2006		

Table 21. Age/length key for segment 10. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**		
	1	**2**	**3**
10			
20			
30	100		
40	100		
50	87.5	12.5	
60	58	42	
70	9	94	
80		70	30
90		29	71
100			100
110			100
Total Number	N = 93		
Sample Years	2005, 2006		

Table 22. Age/length key for Segment 11. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**		
	1	**2**	**3**
10			
20			
30			
40		**No data available for Segment 11**	
50			
60			
70			
80			
90			
100			
110			
Total Number	N = 0		
Sample Years	0		

Table 23. Age/length key for segment 13. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age			
	1	2	3	4
10				
20				
30	100			
40	100			
50	66.7	33.3		
60	24.1	75.9		
70		92	8	
80		66.7	23.8	
90			75	25
100				
110				
Total Number	N = 145			
Sample Years	2004, 2005, 2006			

Table 24. Age/length key for segment 14. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**		
	1	**2**	**3**
10			
20			
30	100		
40	100		
50	53.8	46.2	
60	12.5	87.5	
70		38.5	61.5
80		20	80
90			100
100			
110			
Total Number	N = 102		
Sample Years	2004, 2005, 2006		

Discussion

Sicklefin chubs ranged from age 0 to age 4. Age frequency tables showed a shift from age 1 fish dominating the samples in 2004 and 2005 to age 2 fish in 2006. (Appendix C). It is notable that few age 0 specimens were collected. While age 0 fish were detected, low numbers of specimens suggests that recruitment was low in all years sampled. Another explanation could be that age 0 chubs are difficult to distinguish from one another. Only specimens that could accurately be identified to species were used for age and growth analysis. Sampling bias could account for the lack of age 0 fish. Age 0 sicklefin chubs are not commonly captured by our sampling gears. Habitat preference may also shift with age, with age 0 individuals occupying habitats not frequently sampled. Maximum age for sicklefin chubs appeared to be four years of age from specimens collected from the Missouri River. Few age 4 sicklefin chubs were collected, suggesting that relative abundance may be low due to natural mortality or predation. Overall, 46% of the sicklefin chubs captured were age 2 indicating this size is most vulnerable to our gear.

Mean total lengths increased with age. Though growth slowed with age, lengths did not show a plateau. A positive correlation was observed in all segments between length and age. Because sicklefin chubs are a small bodied and short-lived fish, a sigmoid growth pattern was expected. However, due to the resolution of the data a linear growth pattern emerged.

Mean back calculated total lengths did not show a clear pattern between segments. However, a slight decrease in mean total length was detectable between the upper and lower universes. Mean length-at-capture sizes of age 1 and age 2 sicklefin chubs were significantly larger in the upper sampling universe. This may be a reflection of a short growing season where body size increases with northerly latitudinal gradient and with decreasing temperatures (Stiling 1999). Rapid growth in the early development stages may increase survival rates of small bodied fishes in northern climates (Braaten, 2002). Another explanation may be due to conditions in the channelized portion of the river. Small bodied fishes may have to expend greater amounts of energy to orient or forage in the swifter currents, thereby resulting in smaller average lengths than those in the unchannelized (upper) portion of the river. Due to channelization and flood control levees, the lower portion of the river has also been disconnected from the floodplain. Connection to floodplain food and nutrients have effectively been cut off, thereby limiting access to nutrition needed for growth.

Sicklefin chub specimen collection success has been less successful from the impounded portions of the Missouri River. No specimens were collected from segments 5, 6 and 7 for years 2003 – 2006. As described by Pflieger, sicklefin chubs have a low profile and physiology designed for living in turbid, fast-moving water. Missouri River impoundments create large, deep slack-water lakes with relatively no flow and little shallow water habitat. Water discharge from the reservoirs is relatively clear and may present challenges for sicklefin chubs foraging for prey items. Low turbidity also gives visual predators an opportunity to reduce numbers of small bodied benthic fishes. As an obligate fluvial specialist (Dieterman and Galat 2004), sicklefin chubs are likely extirpated from these highly altered portions of the river.

It is difficult to discern differences in mean lengths between years due to the level of sampling in all segments. Only 2006 reflects an all-encompassing and standardized sampling effort across all segments because of the implementation phase of the Pallid Sturgeon Population Assessment and Associated Fish Community Monitoring for the Missouri River project.

Age/length keys were created, using known age individuals, to be used as a preliminary tool to estimate age of known length individuals. Additional data need to be collected for all segments to create more comprehensive and accurate keys for sicklefin chubs found along the Missouri River. These keys can be used to corroborate the details found in length frequency distributions.

Length frequency distributions for total sicklefin chub captures showed trends in sizes and ages for all segments and years (Appendix B). The length frequency distributions from all segments show an increase in the size classes each consecutive year. These groups of larger individuals show signs of a strong year class spawned in 2004. There were several high water events in 2004 and 2005 which may have contributed to increased sicklefin chub reproduction (Figures 11 and 12). No sicklefin chubs were captured in segment 7 and very few were captured in segment 8. Small fish (less than 60 mm) were rarely captured in segments 3, 4, and 8. It was noticeable, however that overall catch rates decreased every year from 2004 in the Missouri River.

Our findings of mean back-calculated lengths of sicklefin chubs being greater in the upper sampling universe is supported by the length frequency distributions. Length frequency graphs from all sicklefin chubs collected from segments 2 and 3 showed overall length to be greater than in segments from the lower sampling universe. As mentioned previously, one potential explanation for this phenomenon is the need for faster growth in colder latitudes to increase chances for survival throughout the colder winter months.

Age frequencies show that most of the sicklefin chubs processed for age and growth analysis were age 2 followed closely by age 1. As a short-lived fish, one would expect to see age 1 fish more frequently than any other age. Few age 0 fish were found in any year. This is most likely due to our inability to positively identify young of year chubs to species. Chubs that were too small to positively identify to species are coded as "unidentified *Macrhybopsis*" and are not included in these analyses. Few age 3 or older fish were identified in our analyses. This is likely due to the short life span of this species or potential selection by predators, such as pallid sturgeon.

Additional Analyses

Comparisons of age and growth of sicklefin chub, sturgeon chub and speckled chub were performed for 2005 and 2006. Using 998 chubs collected from six segments of the Missouri River, age and growth differences were examined. Multivariate analysis of variance (MANOVA) was used to detect differences of length-at-age by year, species, or between segments.

MANOVA showed a significant effect of year and segment ($P < 0.05$) on length-at-age for chubs less than age-3 (Appendix D). Mean length-at-age-1 was 15%, and age-2 16%, longer in segment 4 than segment 14. Length-at-age comparisons were different among species at all ages ($P < 0.001$). Mean length of sturgeon chub was 13% longer than mean sicklefin chub length-at-age-0, but was 11%, 18%, and 11% shorter at ages-1, -2, and -3, respectively. Chub body length increased 79% (mean = 21.9 mm) from age-0 to age-1. However, increase in body length slowed to 30% (mean = 15.3 mm) from age-1 to age-2, and to 17% (mean = 11.6 mm) from age-2 to age-3 (Appendices E, F)

The additional analyses of all target chub species from 2005 and 2006 show no clear pattern in length-at-last annulus along the river gradient. Upper universe species, however, appear to experience faster growth rates than lower universe species. Although *Macrhybopsis* species appear to have similar ecomorphologies, data suggest that each species experiences different growth rates. Given that, all species show critical ontogenetic growth periods from age 0 to age 1.

Future Recommendations

Typically any bony part will deposit annual growth rings similar to growth rings in a tree. When prepared correctly, counting annuli (rings) of spines and scales can be an accurate method for age estimation in fish. Scales have traditionally been the structure of choice due to ease of and the non-invasive nature of collection. Scales work particularly well for small bodied fishes, such as chubs. However, as fish reach maturity, somatic growth slows and scale annuli become less distinct, thereby producing under-estimates of age. Scales are also prone to regeneration, calcium reabsorption and false annuli which may lead to mis-reading of the scale. Ultimately the subjectivity of interpretation from these structures may reflect inaccurate representations of age structure within populations and lead to negative management repercussions not only for the analyzed species but potentially for multiple species as well (Britton et al. 2004). Recognition of annual growth markings is imperative for determination of fish growth (Pierce et al. 1996). Errors in age estimation can be minimized by incorporating a validation technique. Several techniques are available to researchers but may not be logistically useful in large riverine systems. Age validation techniques include: mark-recapture of fish of known age, marginal increment analysis by way of chemical markers, length frequency analysis and radiochemical dating (Britton et al. 2004).

Compounding the error rates associated with aging small cyprinids, small and inconsistent sample sizes did not allow complete analysis of all segments and years. Because some segments have only one year of data, while others have multiple years, significant results between segments may have been a reflection of low sample size. Additional data is needed from segments in the upper universe to supplement results presented in this report. This is evidenced in preliminary age-length keys, which show many blank fields.

Growth can be evaluated by the size of young-of-the-year (YOY) chubs at the end of the growing season, and by the size of fish ages one and older. A direct indication of growth can be determined by comparing sizes of YOY chubs. Reproductive success can be assessed using relative age class length (Gray et al. 2002). Length frequency distributions may be used in place of age frequency distributions. Length frequency analysis can be used to examine age distributions, size-at-age data, and condition factors for the fish (Gray et al. 2002). Reproductive success can be determined by evaluating the relative abundance of YOY individuals. A length/weight relationship may be used to determine condition factor of the fish. A large number of areas can typically be sampled using this approach and be performed using non-lethal sampling methods. To validate this method, aging structures from size classes analyzed in this report can be used. Length frequency analysis may be a prudent alternative to the current method of estimating ages and life history characteristics of chub species.

Age and growth analyses of all chub species has allowed for an evaluation of annual and long-term trends in population abundance and geographic distribution throughout the Missouri River. Data show that significant size differences exist between segments, species, and years. Because chub species show critical ontogenetic growth periods from age 0 to age 1, conservation and restoration of habitats used by chubs in the first year of life will likely improve survival. Improvement in survival and recruitment of prey species, such as chubs, is imperative to the continued recovery of pallid sturgeon and further restoration of the Missouri River.

Acknowledgments

Special thanks to the staff of all Pallid Population Assessment and Associated Fish Community Monitoring (Montana Fish, Wildlife and Parks, Missouri River Fish and Wildlife Management Assistance Office, Great Plains Fish And Wildlife Management Assistance Office, South Dakota Game, Fish and Parks, Nebraska Game and Parks Commission, Missouri Department of Conservation and Columbia National Fish and Wildlife Conservation Office) for data collection, in the field and in the lab, scientific expertise in data interpretation, and dedication to the recovery of the federally endangered pallid sturgeon. Specifically we would like to extend a thank you to the staff of Columbia NFWCO for assisting with all aspects of this report. Colby Wrasse provided invaluable assistance with literature searches, creating tables, editing and insight for creating this report. . Thanks to Jennifer Johnson, Lee Erickson and Brian Elkington for processing scales, performing age analysis and providing assistance. Thanks to Brett Witte and Cliff Wilson for assisting with literature searches, creating tables and making figures. Clayton Ridenour graciously provided us with the data for the Additional Analyses section. The Columbia FRO has played a pivotal role in the ongoing effort to manage and protect the Missouri River and to promote the overall well being of its native fish fauna. Funding for this project was provided by the Army Corps of Engineers, Omaha District. Appreciation is extended to Yan Hong, Vince Travnichek, and the staff at the Missouri Department of Conservation's Chillicothe Office for maintaining the database. Thanks to Mark Drobish for his flexibility and efforts in facilitating discussion and incorporating changes in the adaptive process of this project.

References

Braaten, P.J. and S.G. Guy. 2002. Life history attributes of fishes along the latitudinal gradient of the Missouri River. Transactions of the American Fisheries Society 131:931 945.

Britton, J. R., I.G. Cowx, G. Peirson. 2004. Sources of error in the ageing of stocked cyprinids. Management and Ecological Note, Fisheries Management and Ecology 11:415-417.

Carlson, D.M., W.L. Pflieger, L. Trial and P.S. Haverland. 1985. Distribution, biology and hybridization of *Scaphirhynchus albus* and *S. platorynchus* in the Missouri and Mississippi Rivers. Environmental Biology of Fishes 14(1):51-59.

Coppage, D.L. and T.E. Braidech. 1976. River pollution by anticholinestrase agents. Water Research 10:19-24.

Dieterman, D.J. and D.L. Galat. 2004. Large-scale factors associated with sicklefin chub distribution in the Missouri and lower Yellowstone Rivers. Transactions of the American Fisheries Society. 133:577-587.

Doyle, W. and A. Starostka, 2003. 2002 Annual report: lower Missouri River pallid sturgeon monitoring and population assessment project. United States Fish and Wildlife Service. Columbia Fishery Resources Office, Columbia, MO.

Doyle, W. and A. Starostka. 2004. 2003 Annual report: lower Missouri River pallid sturgeon monitoring and population assessment project, Segments 13 and 14. United States Fish and Wildlife Service, Columbia Fishery Resources Office, Columbia, MO.

Drobish, M.R. (editor), 2007. Missouri River standard operating procedures for sampling and data collection, Volume 1.2. U.S. Army Corps of Engineers, Omaha District, Yankton, SD.

Gerrity, P. C. and C.S. Guy. 2006. Juvenile pallid sturgeon are piscivorous: a call for conserving native cyprinids. Transactions of the American Fisheries Society 135:604-609.

Grady, J.M. and J. Milligan. 1998. Status of selected Cyprinid species at historic lower Missouri River sampling sites. United States Fish and Wildlife Service, Columbia Fisheries Resources Office, Columbia, MO.

Grady, J.M., J. Milligan, C. Gemming, D. Herzog, G. Mestle, and R.J. Sheehan. 2001. Pallid and shovelnose sturgeons in the Lower Missouri and Middle Mississippi Rivers. Final Report for MICRA.

Jackson, A.L. 2002. Status and characteristics of the sturgeon chub, Macrhybopsis gelida, and sicklefin chub, Macrhybopsis meeki, of the middle Mississippi River. Master's thesis. Southern Illinois University – Carbondale, Carbondale, Illinois.

Gray, M.A., A.R. Curry, K.R. Munkittrick. 2002. Non lethal sampling methods for assessing environmental impacts using small bodied sentinel fish species. Water Quality Research Journal of Canada. 37(1) 195-211.

Jearld, A. Jr. 1983. Age Determination. Pages 301 – 324 *in* L.A. Nielsen and D.L. Johnson, editors. Fisheries Techniques, second edition. American Fisheries Society, Bethesda, MD.

Kallemeyn, L. 1983. Status of the pallid sturgeon. Fisheries 8(1):3-9

Keenlyne, K.D. 1989. A report on the pallid sturgeon. United States Fish and Wildlife Service Report MRC-89-1. Pierre, South Dakota.

Marzolf, R.C. 1955. Use of pectoral spines and vertebrae for determining age and rate of growth of the channel catfish. Journal of Wildlife Management 19(2):243–249.

National Research Council. 2002. The Missouri River ecosystem: exploring the prospects for recovery. National Academy Press, Washington, D. C.

Pflieger, W. L. 1997. Revised Edition. The fishes of Missouri. Missouri Department of Conservation. Jefferson City, MO

Pflieger, W.L. and T.B. Grace. 1987. Changes in the fish fauna of the lower Missouri River, 1940-1983, pp. 166-177. *In:* Community and Evolutionary Ecology of North American Stream Fishes. W.J. Matthews and D.C. Heins (eds.). Univ. of Okla. Press, Norman.

Pierce, C.L., J.B. Rasmussen, and W.C. Leggett. 1996. Back-calculation of fish length from scales: empirical comparison of proportional methods. Transactions of the American Fisheries Society. 125:889-898.

Schmenske, D.W. 1974. Age, length and fecundity of the creek chub, *Semotilus atromaculatus* Mitchill), in central Illinois. American Midland Naturalist 92(2)505-509.

Stiling, P. 1999. Ecology theories and applications, 3rd Edition. Prentice-Hall, Inc. p.52.

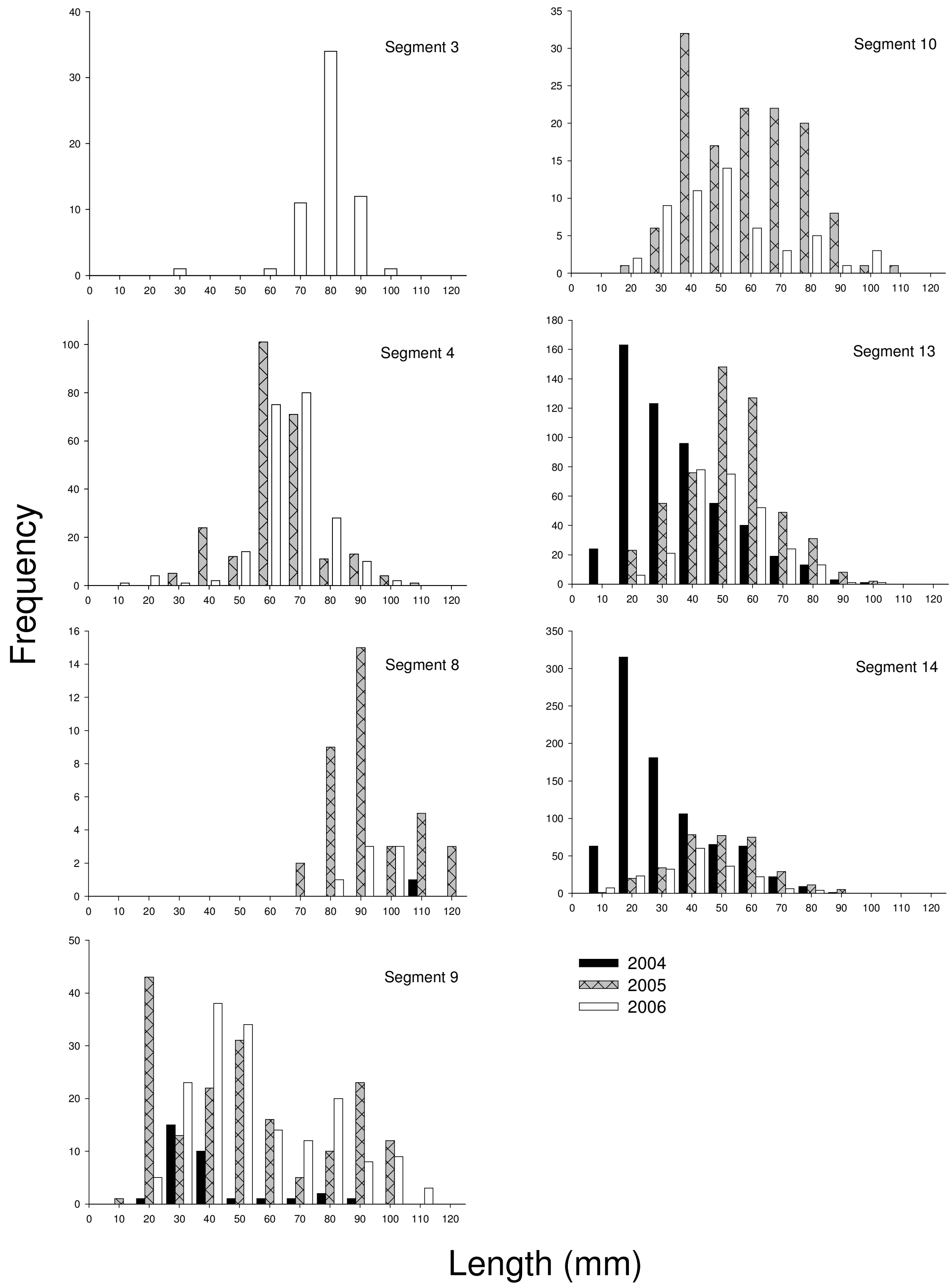
U.S. Fish and Wildlife Service. 2000. Biological opinion on the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River bank stabilization and navigation project, and operation of the Kansas River reservoir system. Fort Snelling, MN.

Wilkison, D.H., D.J. Armstrong, D.W. Blevins. 2002. Effects of wastewater and combined sewer overflows on water quality in the Blue River basin, Kansas City, Missouri and Kansas, July 1998 – October 2000. U.S. Geological Survey Water-Resources Investigations Report 02-4107, 162.

Appendix A. The Y-intercept for back-calculated chub growth by species based on regression analysis by year. The slope value related to each intercept is noted by parenthesis. SFCB = sicklefin chub, SGCB = sturgeon chub and SKCB = speckled chub.

	Segment	2	3	4	7	8	9	10	13	14
2004	SFCB								15.6	13.1
									(109.7)	(110.1)
	SGCB								12.4	15.5
									(105.4)	(100.5)
	SKCB						11.7		12.3	10.4
							(82.8)		(81.4)	(84.9)
2005	SFCB			23.3		50.9	9.3	13.8	16.1	12.1
				(61.9)		(39.9)	(81.6)	(74.8)	(66.6)	(77.4)
	SGCB			8.4		20.8	12.3	13.9	13.3	14.3
				(70.3)		(58.6)	(66.5)	(56.9)	(59.3)	(59.9)
	SKCB					3.8	15.3	4.6	29.7	6.6
						(62.5)	(48.5)	(61.7)	(26.1)	(57.6)
2006	SFCB		21.4	25.1	88.1		5.4	2.4	6.9	6.4
			(70.7)	(57.0)	(8.9)		(89.8)	(88.1)	(84.5)	(78.7)
	SGCB	9.2		10.8			8.0	9.2	6.2	3.2
		(79.3)		(66.8)			(70.0)	(63.1)	(71.0)	(70.7)
	SKCB					15.5	15.2	5.7	14.9	0.8
						(45.9)	(46.3)	(56.0)	(48.2)	(64.1)

Appendix B. Length frequency distributions by segment for all sicklefin chub captures in years 2004-2006.



Appendix C. Age frequency distributions by segment of sicklefin chubs for years 2004 - 2006.

		Segment									
	Age	**3**	**4**	**7**	**8**	**9**	**10**	**13**	**14**	**Total N**	**Total %**
2004	0							7	7	14	11.8
	1							19	17	36	30.3
	2							20	29	49	41.2
	3							5	14	19	16.0
	4							1		1	0.8
2005	0					1				1	0.5
	1		8			15	32	29	23	107	48.6
	2		19		7	5	21	12	7	71	32.3
	3			1	12	12	11	4	1	41	18.6
	4									0	0.0
2006	0									0	0.0
	1		3			9	19	17	1	49	27.2
	2	25	22	1	2	10	10	37	10	117	65.0
	3	5	2	2		4		1		14	7.8
	4									0	0.0

Appendix D. MANOVA table for effects of year, segment, species and interactions of length-at-lat-annulus of chubs in the Missouri River for years 2005-2006.

		Age 0		Age 1		Age 2		Age 3	
Effect	**df**	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Year	1	34.29	<0.001	4.96	0.026	9.5	0.002	0.08	0.783
Segment	5	2.24	0.048	19.85	<0.001	12.94	<0.001	0.56	0.734
Species	2	42.74	<0.001	138.29	<0.001	170.69	<0.001	14.97	<0.001
Year*Segment	5	4.26	<0.001	0.94	0.453	1.2	0.308	0.31	0.819
Year*Species	2	9.82	<0.001	1.72	0.18	3.87	0.022	0.71	0.493
Segment*Species	9	2.88	0.002	3.76	<0.001	5.01	<0.001	0.86	0.525
Year*Segment*Species	9	1.1	0.358	2.86	0.003	2.52	0.008	0.01	0.992

Appendix E. Comprehensive mean back calculated length-at-last annulus for all target chub species in all segments for years 2005 – 2006.

2005												
	Sicklefin Chub				Sturgeon Chub				Speckled Chub			
Segment	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
4		62.5	70.4			53.1	68.0	85.3				
		(3.6)	(1.2)			(2.1)	(1.6)	(8.1)				
8			87.0	95.5		63.0	69.6	85.0		42.0	58.0	75.0
			(2.2)	(1.1)		(0)	(1.4)	(1.5)		(2.3)	(1.2)	(1.8)
9	28.0	51.3	85.6	97.7		42.6	67.5	82.1		38.6	55.0	
	(0)	(3.0)	(6.5)	(2.0)		(3.1)	(4.9)	(2.4)		(1.7)	(1.8)	
10		51.4	76.3	96.2		40.1	52.2	75.5	29.0	35.7	55.4	66.5
		(1.6)	(1.9)	(2.8)		(2.0)	(0.9)	(1.4)	(0)	(1.4)	(1.4)	(4.5)
13		47.9	75.3	86.0		42.3	62.8	76.0		38.9	50.9	70.8
		(1.7)	(1.7)	(2.1)		(3.3)	(3.2)	(1.7)		(1.0)	(1.0)	(0.9)
14		51.1	63.9	95.0		41.3	54.0			38.7	55.8	
		(1.9)	(3.5)	(0)		(1.9)	(2.0)			(0.8)	(3.1)	

2006												
	Sicklefin Chub				Sturgeon Chub				Speckled Chub			
Segment	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
4		65.7	72.7	81.0	37.0	42.5	62.9					
		(1.2)	(2.0)	(6.0)	(0)	(1.5)	(1.2)					
8			81.5				69.0	87.0		38.4	56.2	65.7
			(2.5)				(0)	(0)		(1.5)	(1.5)	(2.2)
9	34.0	42.1	68.7	97.4	34.0	42.9	63.0	89.0	25.5	41.3	58.6	69.3
	(0)	(1.4)	(2.1)	(3.4)	(0)	(1.7)	(2.2)	(0)	(0.5)	(1.7)	(1.5)	(3.2)
10		45.9	70.7			36.2	52.8			37.7	56.3	64.8
		(2.0)	(2.7)			(1.3)	(2.6)			(1.1)	(2.0)	(1.2)
13		40.0	70.6	90.0		37.8	57.7	85.3		38.7	56.3	70.8
		(2.1)	(1.7)	(0)		(1.9)	(1.4)	(4.7)		(1.1)	(1.3)	(1.3)
14		59.0	64.4			42.5	50.0		30.0	36.9	53.5	
		(0)	(1.4)			(2.5)	(1.2)		(0)	(1.4)	(1.5)	

Appendix F. Summary of mean back-calculated length-at-last annulus for sicklefin chub, sturgeon chub and speckled chub for years 2005 - 2006.

Age	Sicklefin Chub	Sturgeon Chub	Speckled Chub
0	31.0	35.5	28.2
1	50.9	45.1	38.7
2	73.2	60.4	55.6
3	92.0	82.1	68.6